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Technology Review

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10 EMERGING TECHNOLOGIES 2010

Real-Time Search
Solar Fuel
Mobile 3-D
Engineered Stem Cells
Light-Trapping Photovoltaics
Social TV
Green Concrete
Implantable Electronics
Cloud Programming
Dual-Action Antibodies

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COVER
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45 10 Emerging Technologies

Real-time search. Biofuels from photosynthetic microbes. Engineered stem cells. Green cement. Our annual list of the emerging technologies that will have the biggest impact on our world.

By TR EDITORS

■ **www.technologyreview.com/tr10** Watch video reports on the technologies featured in the TR10.

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THE REVOLUTION'S COMING; IT'S JUST SLOW

As a Parkinson's disease activist and a customer of 23andme, I see the potential revolution in personalized medicine (Briefing, March/April 2010) from a vantage point that is between ringside and in the ring. Personalized medicine is developing on three time scales. The fastest is the improvement in genome sequencing, which is proceeding at the speed of competing startups. A slower process involves elucidating the relationships among genetic markers, diseases, and the safety and effectiveness of treatments. Even slower are changes in medical practice: many professionals must change the way they think and act to account for patients' differences. The evolution of personalized medicine is likely to be a long, wild ride.



March/April '10

H. Paul Zeiger
Denver, CO

New science is changing the taxonomy of disease and allowing for targeted therapies. As CEO and founder of Genomics Healthcare Strategies, I think progress is uneven because of the complexities of underlying biological processes and the difficulty of changing a health-care system focused on treatment. Molecular medicine's biggest impact will be changing the economics of health care. Aside from improving care and lowering costs, it will change where and how we buy health care. New sources of information will create competition. Organizations that best demonstrate products with a clinical and economic benefit will be winners in these new markets.

Keith Batchelder
Charlestown, MA

HOW ACADEMICS HINDER INNOVATION

Politics is only one small part of why U.S. Small Business Innovation Research (SBIR) grants have produced very little innovation ("Publicly Funding Entrepreneurship," Notebooks, March/April 2010). Those grants go to university researchers because reviewers expect the grantee to have published articles, and these researchers are in a publish-to-survive mode. But ideas from small businesses are proprietary and therefore are not publicly available prior to commercialization, which means they lack a publication trail. For SBIR awards to yield products, stop having academics review grants. Small companies live or die on innovations; universities don't.

Richard McDonald
Henderson, NV

LASERS BRING BACK THE MEMORIES

I'd like to correct a possibly misleading impression in "Year of the Laser" (March/April 2010). The first reference to a laser (after Einstein) should be attributed to Arthur Schawlow and Charles Townes. Their 1958 paper in *Physical Review Letters* described the physics of "coherent laser light," letting experimentalists evaluate the qualities of their laser light output. As a senior scientist at the Livermore Laboratory, I appreciated the image of the Nova laser. Our groups at Livermore spent 30 years working to build this 10-beam laser and used it to demonstrate inertial fusion; it's exciting that fusion ignition and gain demonstrations are beginning using the 192-beam NIF laser.

John F. Holzrichter
Berkeley, CA

GET-WELL CARDS FOR CAPITALISM

I read your From the Editor column "Sick Capital" (March/April 2010) with pleasure. When your investor lamented that today's VC investors spread themselves too thin, I had to smile. I had the same experience 30 years ago with my first startup. Well-known investors would roll in for the board meetings, ask some off-base questions, and fly off again. Your list of 50 innovative companies (TR50, March/April) tells me that opportunities in venture investing are mostly in biotech or materials-based technology, both of which need prodigious investment but could offer commensurate returns.

Sumin Tchen
Concord, MA

UNLEASHING MATH ON THE WORLD

Great article on "Turning Math into Cash" (March/April 2010). It shows how brainpower is expanding IBM's offerings beyond what's conventional. But, given the results of mathematicians running the financial industry, we might not want to let them run the world.

aunderdown
(Alan Underdown, Ottawa, Ontario)

Were those complex mortgage securities accepted by decision makers because mathematicians provided assurances? Or was it seen as a way to hide risk and promote sales?

rphair
(Robert Phair, Los Altos, CA)

I wish I knew. Many financial analysts believed that markets are efficient. Math models can facilitate foolishness, but that's not the math's fault.

aunderdown

IBM's move toward consulting is smart. The mathematics behind analytics can convince managers of things they should have done long ago. I long to see the day when companies use analytics in decision-making. Plus, IBM's consultants can set up analytics studies so that the right items are measured for the most effective insights.

briang1621
(Brian Glassman, Pembroke Pines, FL)

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NOTEBOOKS
Expert opinion



ENERGY

Biofuel Backlash

C. FORD RUNGE EXPLAINS HOW SUBSIDIES FOR CORN ETHANOL ARE HURTING PEOPLE AND THE PLANET.

Subsidies for biofuels in the United States have reached levels unimagined when support for an "infant industry" began in the late 1970s. Today, the infant has grown into a strapping behemoth with a powerful sense of entitlement and an insatiable appetite for ethanol's primary feedstock: corn. In 2009, the U.S. Department of Agriculture reported a record corn harvest of 13.2 billion bushels, 9 percent larger than the harvest of 2008. Ethanol production consumed more than a quarter of that crop—enough to feed 330 million people for a year, according to the Earth Policy Institute, an environmental organization in Washington, DC.

Apart from subsidies paid to blenders of ethanol (passed along as higher prices to farmers), the industry is supported mainly by laws mandating ethanol blending, escalating from 12.95 billion gallons in 2010 to 36 billion gallons in 2022. President Obama has proposed extending this mandate to 60 billion gallons by 2030. If there is one thing the United States has an uncontested comparative advantage in producing and exporting, it's corn. But when that corn is turned into ethanol, it requires 54 cents a gallon in tariff protection to compete with Brazilian sugar-based ethanol—demonstrating a clear *disadvantage*.

Doug Koplow, founder of the energy consulting firm Earth Track in Cambridge, MA, has calculated that the combination of tax credits, mandates, and tariffs will cost taxpayers $400 billion from 2008 through 2022, assuming that the mandated targets can be met. Eventually, 16 billion gallons are to come from cellulosic biofuels—yet not a drop of such fuels is now being commercially produced. If President Obama's target becomes fact, the cumulative taxpayer cost of subsidizing biofuels will exceed $1 trillion by 2030.

It would be one thing if—as advertised—these subsidies had no adverse impact on food prices, encouraged the substitution of homegrown energy for foreign petroleum, and reduced the energy sector's carbon footprint. But evidence suggests the opposite. Perhaps the most salient recent criticisms of biofuel policy relate to their impact on the environment. A worldwide agricultural model estimating emissions stemming from changed land use found that corn-based ethanol will nearly double greenhouse emissions over 30 years and increase greenhouse gases for 167 years.

The Environmental Protection Agency has been forced to reduce the amount of cellulosic biofuels mandated for 2010 by 94 percent—from 100 million gallons to a mere 6.5 million, all of it produced at heavily subsidized pilot plants. When cellulosic or other alternative biofuels *(see "Solar Fuel," TR10, p. 48)* will begin replacing today's corn- and soybean-based fuels is anybody's guess, but it won't be tomorrow, and it may be never. Who really thinks the corn growers' associations, and major ethanol producers, will hand their subsidies over to grass? TR

C. FORD RUNGE IS THE DISTINGUISHED MCKNIGHT UNIVERSITY PROFESSOR OF APPLIED ECONOMICS AND LAW AT THE UNIVERSITY OF MINNESOTA. THIS ARTICLE IS BASED ON A STUDY CONDUCTED WITH ROBBIN S. JOHNSON FOR THE WOODROW WILSON CENTER FOR SCHOLARS, IN WASHINGTON, DC.



NICK REDDY/HOFF

INTERNET

Updating Search

WE NEED TO REIMAGINE THE ROLE OF SEARCH ENGINES AND THEIR SOURCES OF DATA, SAYS SHASHI SETH.

Real-time search means retrieving information about what's happening, everywhere, now. The amount of real-time data that's available is growing rapidly with the proliferation of mobile devices. At Yahoo, we have already begun to incorporate real-time search results from Twitter and sources of developing news. But the scope of real-time data reaches far beyond tweets and


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Facebook updates. For example, users are uploading photos on Flickr to show what's happening around them, chatting about the latest news, and answering questions live on sites like Yahoo Answers. That's just the beginning of the real-time information that can be made available to search engines *(see "Real-Time Search," TR10, p. 46)*.

The sheer amount of real-time data presents unique challenges for search. Because a lot of the data is nonauthoritative, noisy, or spammy, search engines need to build trust models that can determine what data is important and influential. For example, retweets are not often useful results, and some data providers carry more authority than others. Search engines must also determine the right balance between timeliness and relevance to each user. Further, real-time data needs to be indexed and updated instantaneously. A few years ago, search engines took several hours to index. Today, they take only a few seconds—but they need to become even faster.

With the challenges of using real-time data come some exciting possibilities for reimagining search. As in the early days of the Web, when Yahoo built a directory to identify authoritative sites, we are seeing search engines building better trust models. Aggregators are emerging to qualify the reputations of sources. Many other types of self-organization are possible in this new realm.

We can imagine that to speed up the rate at which search engines are able to share real-time data, some sources will inform their indexes when something is happening. Rather than just waiting for search engines to crawl a site, users can push relevant new information. Say you are looking for a parking space in busy downtown San Francisco: parking lots might send updates to search engine indexes as spaces become available.

Already, we know that real-time search can serve needs other than those of traditional Web search. The resulting data can be invaluable in answering long-tail queries—those that aren't related to the most popular topics. The potential uses of real-time search are limitless. Finding—and inventing—new uses will make search even more valuable in our daily lives.

SHASHI SETH IS SENIOR VICE PRESIDENT OF SEARCH PRODUCTS AT YAHOO.

MEDIA

Online Video

NEW TOOLS ARE HELPING VIDEO BECOME PART OF THE FABRIC OF THE WEB, WRITES MICHAL TSUR.

Viewing of online video more than doubled during 2009: the number of videos watched rose from approximately 15 billion in January to more than 33 billion in December. At the same time, the tail of the phenomenon grew longer. The top 10 video sites accounted for more than 56 percent of online views at the beginning of 2009, but by the end of the year, they accounted for only 52 percent. Smaller news and media sites, social networks, university sites, corporate sites, and, most recently, e-commerce sites have all been supplementing their offerings with video.

At Kaltura, a provider of an open-source video platform, we've seen a massive increase in demand for online video solutions among universities and organizations, which made up 3 percent of our customer base at the beginning of 2009 but accounted for more than 20 percent of new customers at the beginning of 2010. Universities use videos in distance learning and online course work. Companies use video for employee training and knowledge sharing, and also for corporate and product marketing. Governments use video as yet another channel for communication. And e-commerce



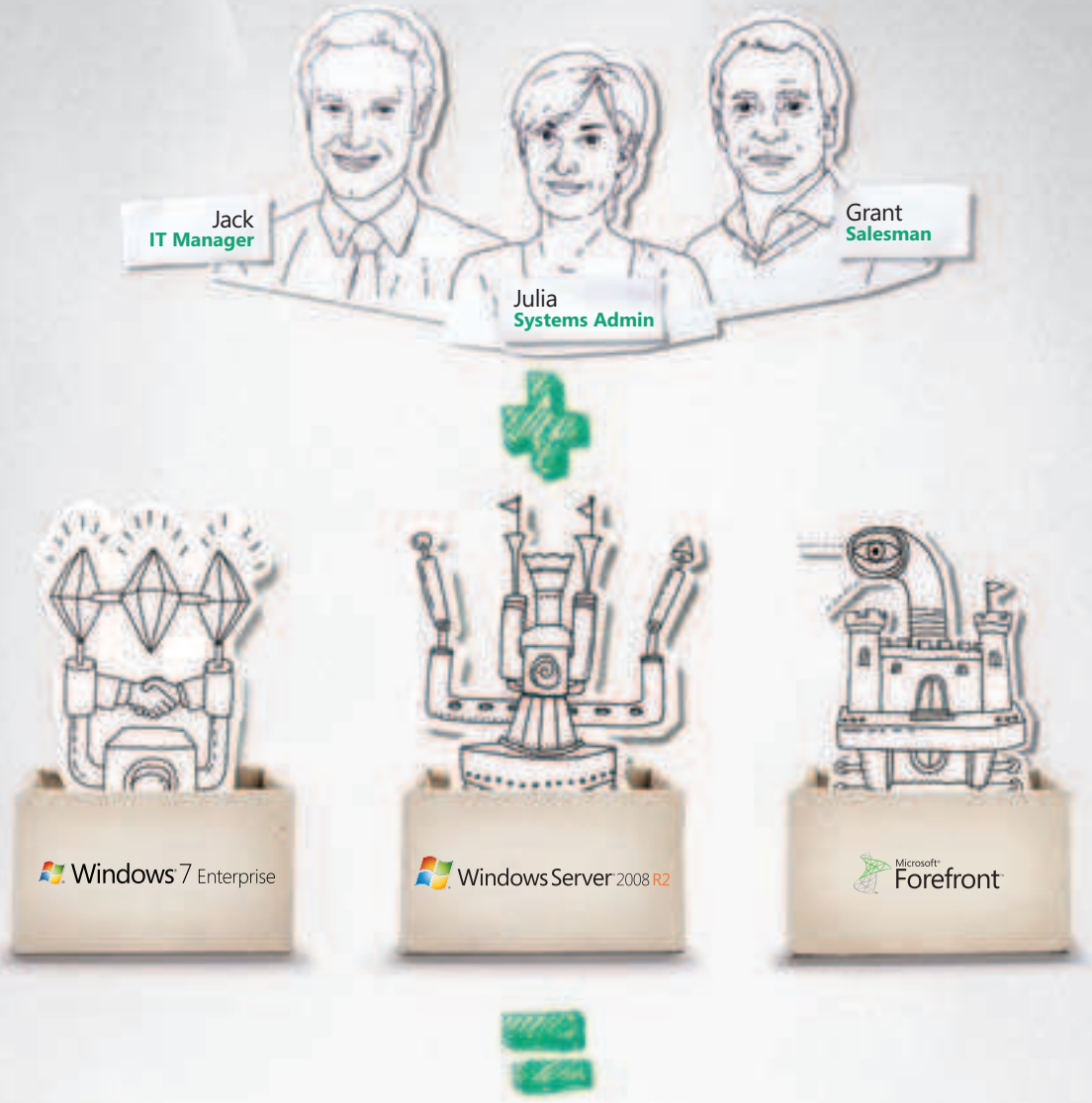
sites, such as Zappos, have recently found that video offers even better conversion rates than still images.

Once upon a time, you could only sit back and watch the videos. Now you can search videos, trim them, annotate them, remix them, and send them to friends. These new possibilities are bringing video to a broader range of users. And this broader use is driving the development of new tools to specialize video for different users. Universities, for example, are looking for ways to search video libraries and archives. Many users need tools that make video as easy to edit as text, or ways to sync video with documents and PowerPoint presentations. Wikipedia, which only recently incorporated video into its strategy, will lead this market with fully collaborative video, featuring tools for video manipulation and search. Publishers want to have a dialogue with their audience, and sometimes even to crowdsource production efforts. News sites want to spread citizen journalists' hottest video news. E-commerce sites want video as a medium for selling products and as a way for customers to review their purchases.

Online video seems to have been here for a long time, but it has actually been widely available only for the past five years or so. For sure, it will get better, faster, and easier to use, and it will continue to extend its reach *(see "Social TV," TR10, p. 55)*.

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A TR10 Primer

WHAT THE 10 TECHNOLOGIES TELL YOU ABOUT US.

Every year, the editors of *Technology Review* pick the 10 new technologies we think are most likely to change the world: the 10 emerging technologies, or TR10.

Other lists we create—and such lists are an unavoidable feature of modern publishing, produced in large part because you, our readers, like them—are more objective. We select the TR35, our list of the 35 young innovators under the age of 35, after considering grades that a college of distinguished judges assign to a long list of candidates (nominated by the innovators' peers and bosses). The TR50, new this year, is our list of the 50 most innovative companies on the planet: *they* were chosen by filtering econometric data—such as the ratio of a public company's investment in research and development to its generation of intellectual property, or the size and sources of a startup's funding—through our opinions of the companies' products and services.

But the TR10 are the 10 emerging technologies of the year because we say so. They are fruit of the previous year's reporting by the editors, and they inevitably reflect our emphases and biases. What do they say about us?

Identifying and analyzing emerging technologies is the special mission of *Technology Review*. To say all 10 technologies are "emerging" means they are leaving the laboratory or development and are being commercialized but are not, in most cases, widely used in products or services. However, the novelty varies: in general, the software has been developed most recently, the materials more distantly, and biotechnology somewhere in between. For example, Google and Microsoft's Bing have been searching social networks like Twitter and Facebook since late last year *(see "Real-Time Search," p. 46)*, and the technology that enables them to do so is only a few years older. By contrast, while the particular approach we describe to developing concrete that absorbs more carbon dioxide than is released during its manufacture is the result of relatively recent work by Nikolaos Vlasopoulos at Imperial College, London, and at his startup Novacem *(see "Green Concrete," p. 56)*, others have been tinkering with ways of creating cleaner cement since the 1970s.

We wanted technologies whose potential impact was very striking. Our main method for evaluating potential impact was to find a big, persistent problem. For instance, ever since the introduction of combination chemotherapy in 1965, doctors have wanted to reduce the number of drugs in therapeutic cocktails while still hitting multiple drug targets. That's because a single drug that acted multiply would outwit the tendency of cancer cells to acquire resistance to individual chemotherapy medications. In "Dual-Action Antibodies" *(p. 60)*, we describe how last year the biotechnology company Genentech created a modified version of its blockbuster drug Herceptin, a monoclonal antibody that shuts down a growth accelerator protein in breast tumors. The new version also blocks a protein that stimulates the formation of tumor-feeding blood vessels—the mechanism of another blockbuster Genentech drug, Avastin. Dual-action antibodies could be a significant advance in treating cancer.

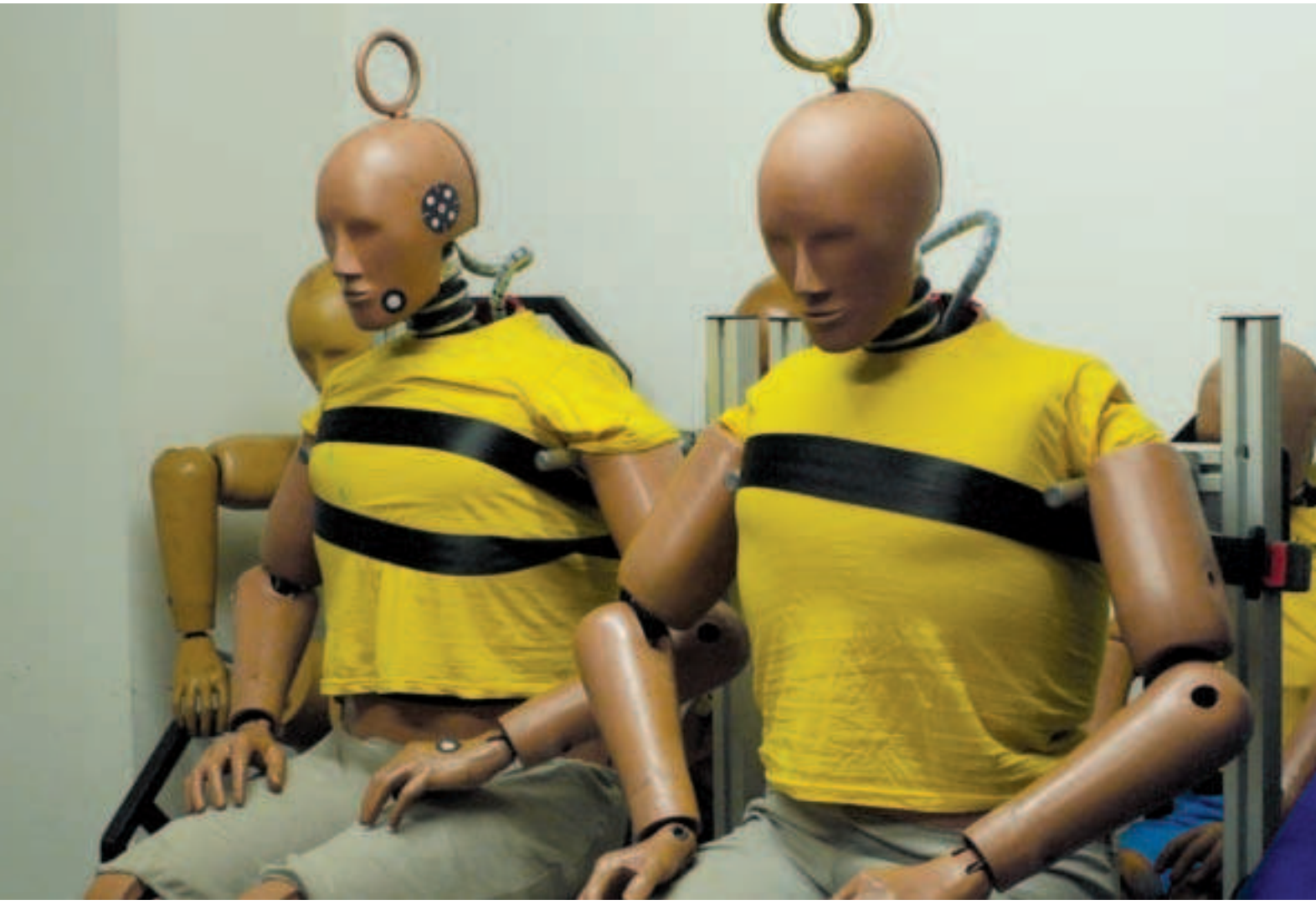
But more than anything we valued elegant solutions to persistent problems.

Consider: today, solar energy accounts for less than 1 percent of energy used in the United States. The main reason is cost. To convert sunlight to electricity, we can use efficient but expensive photovoltaic cells made from crystals of the same silicon used in computer chips, or we can use solar cells made from films of semiconducting materials that are cheaper but less efficient; but we don't know how to make cells that are efficient *and* cheap. Now, by harnessing plasmons—a type of wave that moves through the electrons at the surface of a metal when they are excited by light—we might do both *(see "Light-Trapping Photovoltaics," p. 54)*. Researchers at the University of New South Wales and other universities discovered that by depositing nanomaterials on the surfaces of thin-film photovoltaic cells, they could exploit plasmons so that photons "bounced back and forth within the cell, allowing longer wavelengths to be absorbed." That's a cool idea: it neatly transcends the limitations of current technologies.

Finally, this year's 10 technologies, beyond displaying the editors' tastes for novelty, difficulty, and elegance of conception, are a testament to our optimism. They expand human possibility by supplanting established ways of doing things. For decades, almost everyone who wanted to replace fuels made from hydrocarbons worried about which biomass to use, even though it wasn't clear how we would grow the biomass or efficiently turn its sugars into fuel. They simply asked: corn, switchgrass, or algae? In "Solar Fuel" *(p. 48)*, we describe an effort to engineer photosynthetic microörganisms that use sunlight to convert carbon dioxide directly into ethanol or diesel. *That* is the kind of thing we like: it has the blithe confidence of magic.

But write and tell me what you think at jason.pontin@technologyreview.com. *—Jason Pontin*

MARK OSTOW



INVESTING IN SMARTER RESEARCH

Enabling small and medium-sized businesses to invest in research and innovation, a network of Spanish research centers provides support and infrastructure to help these organizations develop new technologies for a changing world.

In a cavernous hall in Valladolid, Spain, test vehicles can plow into a wall at speeds up to 125 miles per hour. This high-speed facility for materials testing and vehicle safety, housed in the Research and Development Center for Transportation and Energy (in Spanish, Cidaut), provides both automotive and materials companies—as well as Cidaut's own researchers—the tools needed to test novel materials and evaluate the safety of different forms of transportation.

Cidaut is part of a private association of Spanish technology centers, whose organizing body is known as Fedit. Fedit comprises 67 such centers around the country; some of them have been in existence since the 1960s.

For decades, Spain functioned largely as a manufacturing facility for the rest of Europe, importing new products and technologies from outside the country. "We realized that we needed to improve our products if we wanted to compete," says Diego Lafuente, director of the network of Fedit centers. But not so long ago, most Spanish companies were small—often family-owned—businesses, and lacked the capital to invest in appropriate tools for in-house R&D. Then, in order to compete, companies in complementary fields began to pool their resources and form privately-funded research facilities. These centers also work in partnership with local universities and governments.

PHOTO COURTESY OF CYNTHIA GRABER

"These technology centers were created to be close to the market," says Ricard Jiménez, scientific director of Ascamm, a materials research center in Barcelona. "We work for industry and conduct research and development, and the goal is to sell a final product."

There are many different models for these partnership centers. Cidaut, for instance, which works primarily in transportation and energy, may develop new technologies for companies that produce automobile parts. Or technology center researchers may work simultaneously with companies that compete directly against one another. At times research projects are formed as partnerships among companies and centers, while in other cases the center may sign exclusivity and confidentiality agreements with a single company.

> "Our [research] ideas are generated by the fact that we work in the real world, every day, with companies."

At least 51 percent of the shares of each technology center are owned by private companies, while the rest may be held by universities and local and national associations. At least 40 percent of center funding comes from contracts with private companies, and the remainder is sourced from competitive local, national, or EU grants. "It's an unusual model," says Lafuente of outsourcing R&D to private research centers, but it works. The centers have a track record for enabling the creation of patents, new products, and spinoff companies, and Fedit has shown that they also demonstrate the payoff of R&D investment to small companies, which may not have realized their potential in the past. One Fedit study shows that an increase in private R&D investment over the past five years can be attributed to the work of the technology centers.

The centers can also help guide company research. "If centers work with a variety of companies in a particular field, they gain a great deal of expertise," observes Lafuente; that expertise in turn enables these technology centers to anticipate the needs of the marketplace. Juan Carlos Merino, director of Cidaut, agrees: "Our [research] ideas are generated by the fact that we work in the real world, every day, with companies."

TRANSPORTATION

Cidaut's high-speed crash test facility, which can move up to 700 kilos at more than 100 times the acceleration of gravity, is just one of the services it provides to its customers. At the same time, the center's original work in molds and manufacturing for automation has expanded into materials, manufacturing processes, and products for transportation, energy and the environment. Its lab allows characterization of materials and composites on the nanoscale. Its services have resulted in a variety of successful enterprises, including a spinoff company (Aleaciones Ligeras Aplicadas), which designed components for the new Alfa Romeo.

At the applied mechanics department of the CEIT research center, visitors can step into a reconstructed truck cab. Through the front window, a simulator projects the driver's route on a screen ahead. Grasping the gear stick, the driver feels resistance as the transmission shifts into first, then second gear. Then the wheels resist as the driver turns the steering wheel and navigates down the road.

This combination of imagery, motion, and haptics technology was originally created by CEIT engineers for driver training. CEIT has already created a spinoff company, Lander Simulation, to market simulators for automotive and railway training to companies around the world. Together, CEIT and Lander are now researching an intelligent simulator that can learn from expert drivers. This will increase the simulator's expertise at teaching other drivers how to cope with extreme driving conditions.

As their expertise in haptics and virtual and augmented reality has increased, CEIT engineers have expanded their virtual reality programs to assist in additional business sectors. For civil engineering, they're designing a simulator to allow machine operators to "experience" drilling into rocks before they begin work on a new tunnel.

Emilio Sanchez, head of the robotics department, points out that the team has also moved into health care: it is working with surgeons to develop a program that emulates the feel of drilling into a skull. "If the doctor doesn't have total control of the drilling process, he or she could damage the brain—or, in maxillofacial surgery, an important nerve. So instead of doing this training protocol on a corpse, let's use a haptic device," says Sanchez. The team is closely coordinating its efforts with local hospitals and neurosurgeons.

MATERIALS OF THE FUTURE

Carbon nanotubes hold out the promise of endowing the next generation of polymers with characteristics such as dramatically increased strength and resistance, even as their weight decreases. To develop these novel composite materials for fields such as transportation, health, and agriculture, a consortium of research centers, including Tekniker, Gaiker, and CEIT, are working together. For the agricultural sector, for instance, they're developing films

A NOVEL ENGINEERING PERSPECTIVE

To aid in making more precise measurements for meteorology, transportation, and aviation, the research center Tekniker, in partnership with the Spanish Center of Metrology, has developed the world's most precise barometer. Over the ten years of research it took to develop this tool, and building on its decades of creating tools for scientific research, Tekniker decided to approach this challenge from a novel engineering perspective. Instead of, say, measuring through ultrasound as the North American version does, the Tekniker barometer relies on a technique called laser interferometry. The barometer consists of two connected columns of mercury topped by a float that supports a laser reflector. The exact position of the mercury is measured by combining light from different receptors to create a high-resolution image.



that can allow the passage of only specified wavelengths of light. These films could help to control temperatures in a greenhouse, and stimulate plant growth at the same time.

One of the most significant contributions of these composite materials could be to the automotive and aeronautical industries, as engineers create materials that are significantly lighter, yet able to absorb impacts. The carbon nanotubes in the polymers give them the ability to spring back into shape after they are struck and deformed.

But developments in materials science are not limited to carbon nanotubes. CTM's experience in manufacturing and machine-tool development has allowed that center to lead in the creation of new surfaces for the machine tools that must handle these new, highly resistant components. The new parts for automobiles, made out of lighter, highly resistant composite materials, can cause rapid wear and tear, even to the breaking point, on the tools used to make them. In response, CTM and partner companies developed new steels, with molecular structures that allow them to form these parts without being ground down themselves.

The AIN center has traditionally assisted automotive companies in developing components with enhanced properties to resist higher temperatures or bear higher loads. Today they're applying that materials expertise to development of a surface coating for stents to increase blood flow. Since the growth of cells on stent surfaces can interrupt the flow of blood, AIN engineers developed an immersion treatment to coat the complex surface of the stent by bombarding it with ions. This bombardment creates an oxide layer that prevents cells from attaching to the stent wall. AIN engineers are also developing coatings to prevent surface wear on metal prostheses.

The nanotechnology research team at Ascamm, a center outside Barcelona, has partnered with the local Nanotechnology and Nanoscience Investigation Center to develop a polymer that can adhere to any surface and give it superhydrophobic properties, so that water (or any other liquid) will roll right off. "We as scientists know how to work in the lab, but Ascamm knows how to scale up and work with industry, providing a bridge" between scientists and companies, according to Daniel Ruiz, a researcher at NNIC.

Ruiz and his colleagues have created a proprietary material of fluorinated chains, which adheres to a surface with only a single dip into the coating. This would be easy to integrate into manufacturing and is both more environmentally friendly and easier to apply than the products now on the market, says Ruiz, and could be useful for many industries, including textile and automotive enterprises.

Researchers at Cetemmsa, outside Barcelona, are taking materials science to the textile sector. They've developed conducting threads that heat up or become illuminated in response to a charge; these might be used in sports applications. They're also involved in an EU project to develop a textile for photovoltaic energy, with the goal of someday creating a shade, perhaps even an umbrella, that can also serve as a photovoltaic panel.

Cetemmsa has also applied this electronic textile concept to the health sector, creating a skin patch that releases the active material only when and where the user wants it, as opposed to the slow, continuous release available in today's patches. A slight charge triggered by a battery will cause a barely discernable temperature change in the fabric, and warm up the nanocapsules (developed by project partners) that contain the active ingredients. Stopping the charge would halt the release. Cetemmsa is now working with dermatologists to design a patch like this for use with skin treatment products.

HEALTH AND WELLNESS

Materials science is just one area in which the network of technology centers is assisting the health and wellness sector. Gaiker, located in the north of Spain, employs genomics, proteomics, and metabolomics to investigate the ways in which cells respond to chemicals, drugs and natural compounds. Gaiker is working on a number of EU projects to identify and develop in vitro tests that can replace animal tests for cosmetic and pharmaceutical safety.

"These tools allow you to see the reaction of the individual cells, and of course an animal is a pool of cells,' says Oscar Salas, Gaiker's international projects coordinator. "This can represent the future behavior of any kind of substance in human beings." These international projects are intended to aid cosmetic companies in replacing animal tests, since the EU has announced these must cease by 2013.

Gaiker scientists have also patented a biomarker for colorectal cancer and are partnering with research institutions across Europe to develop new nanoparticles for diagnostics and therapies for different kinds of cancers. This field of research has also led them into work on a lab-on-a-chip, which could be set on devices like intelligent phones to evaluate biomarkers, then send information to doctors.

Creating sensors like these may be aided by manufacturing developments at Tekniker, which is developing nanofluidic devices that measure various parameters of blood. Tekniker has created a device with channels less than 100 nanometers wide that will allow DNA samples to be stretched over the length of the channel; measuring the length of the DNA sample will allow for its characterization. The process by which they've formulated the nanochannels, known as nano-imprinting, can, Tekniker researchers say, be easily reproduced for high-throughput manufacturing, and could be used for disease diagnostics and for determining appropriate treatments.



Ascamm's robot (above) can take a 3-D image and create a model of it. While such a model can be used to sculpt virtually any object, obviating the need for single-use molds, Ascamm, in partnership with the Orthopedic Technical Institute in Barcelona, has also developed a robot-assisted process for building a prosthesis. First the patient's leg is scanned, then that image is transformed into a 3-D model using CAD. The CAD model is passed to the robot, which then builds a completely custom-designed prosthesis.

Many research centers are working on robots and the parts they need, such as sensors for artificial vision. Tekniker has created a robot complete with x-rays and artificial vision to evaluate defects in seat belts. And AIN is taking part in a project to develop the mechanics and flight controls for unmanned helicopters to monitor power lines; this requires building a system that can overcome and cancel out interference from electrical fields.

SURGICAL CLOSURES

After many grueling hours of brain surgery, it's finally time for a surgeon to close up the skull. This is no simple matter. The metal products today on the market require surgeons either to position a clamp carefully and exert pressure on it without damaging the brain, or manipulate tiny screws into a metal plate. Both methods present challenges: a clamp's rough edges can injure the brain, while tiny screws may test the patience of a surgeon finally reaching the end of a long process. And the metal in either product may interfere with future tumor diagnostics and treatments.

In response, a team of neurosurgeons, materials scientists, and manufacturing engineers have teamed up to create new close-up products, and formed a new spinoff company—Neos Surgery—from two research centers, Ascamm and Inasmet.

Neos Surgery's first product is a device to clamp two pieces of a skull back together, using a shape-changing nickel-titanium alloy that responds to heat–in this case, body heat. The device is kept cold in a refrigerator. When the surgeon is ready to close, she can position the clamp at the section of the skull to be attached. Immediately the coil begins to tighten, the clamp to close.

The success of this first product led to the development of a second, the Cranial Loop, made entirely of polymers. Two pieces of skull are fastened together by inserting the tiny device and applying the necessary pressure until the fit is snug; no plates, screws, or other instruments necessary.

"Instead of pushing on the skull, you just cut off the edges [of the Loop]," says Lluis Chico, Neos' general manager, and the

PHOTO COURTESY OF CYNTHIA GRABER

entire process takes only seconds to complete. The polymer fits smoothly against the skull and creates a surface with no sharp edges. This is the only such product on the market made totally of polymers, therefore causing no interference with future CT scans or MRIs.

The Cranial Loop was met with enthusiasm at the World Congress of Neurological Surgeons in Boston in September, 2009, says Chico: "Surgeons said, 'Finally, there's a new fix to help make cranial-neurosurgery easier.'"

Ascamm worked closely with the product developers to create the appropriate manufacturing conditions necessary for a polymer device of such a small size, with miniscule edges for closure. "We were limited by manufacturing," says Chico. "[Ascamm] engineers studied the mold, the process for injection, and the plastic itself. With their help, we were able to convince manufacturers that it was possible."

That microinjection process will find a major market, notes Ascamm Director of Corporate Development Myriam Garcia-Berro: "There's a tendency towards miniaturization that those in the medical field are demanding, and in electronics as well … and there isn't a great deal of knowledge or technology yet on microinjection."

According to Chico, these two products have applications for additional cranial and spinal surgeries. Shape-changing material could be used, for instance, in minimally invasive spinal surgery, where the product could be implanted while tightly coiled, then expand, warmed by the patient's body heat, to a degree specified to decompress an area of the spine.

Neos Surgery is already selling its products in nine countries in Europe, and it plans to expand internationally.

FUTURE OF FOOD

In a stark white building, with light flooding the windows and through glass walls into the offices and labs, Ainia scientists are investigating several aspects of food production and monitoring and applying lessons learned from food research to other sectors. Says Miguel Blasco, Director of Research and Development, "The design of the building represents our center's philosophy: clarity, transparency, and integration."

Ainia's scientists have been working with food companies in the Valencia region and around Spain for decades, undertaking projects like helping vintners ensure more consistently high-quality wine production, and improving packaging to prevent spoilage of lettuce greens. The center today operates on an international scale, offering its services and research expertise on topics related to food quality and safety.

Ainia has developed a test for microorganisms that can yield results in only 10 hours instead of three weeks. It is working on methods of identifying contamination using biosensors, and is also cooperating in the development of cameras with multispectral vision to classify agricultural products and identify defects or contamination in them. The nearby research center Aido, meanwhile, is providing the optical technology expertise for machine vision.

The packaging and logistics center Itene has employed its nanoparticles division to investigate improved food packaging, leading an EU project to develop materials that will include a microbial agent to extend shelf life. Itene researchers are also developing an intelligent packaging system, which in the future may include radio frequency tags for a shipment's location and conductive inks to communicate the temperature of a container, helping to prevent a shipment of produce from getting too warm and spoiling. "So far, this new system is expensive, but I think it will get to the market in a few years," says Carmen Sanchez, Itene's associate director, "because it's expensive for companies now to solve these problems when they occur."

Active packages like these are also a prime research focus of the National Center for Food Technology and Safety (CNTA). Originally born of an association of companies devoted to vegetables, the center has since expanded to work with companies across all aspects of food production.

The food industry hopes to use more food-derived antioxidants, such as resveratrol from grapes, both for their health benefits and to prevent spoilage. So CNTA researchers have been working to develop ways to stabilize these compounds by micro- and nano-encapsulation. The resulting process could either protect the compounds during the transportation phase, until they are integrated into the food, or encapsulate them until their coating is destroyed in the stomach. These processes are currently being patented, and CNTA is spinning off a company to market the results.

ENVIRONMENTAL IMPROVEMENTS

As focus on renewable energy and reducing greenhouse gases continues to grow worldwide, Cidaut has turned its attention to a technology that already has reached a wide international market: the solar-powered water heater. The basic technology consists of collecting the sun's rays to heat water, then using that hot water for the building's needs. Cidaut's Merino says there are many improvements in efficiency to be made, which could provide significant savings by heating more water in a smaller space at a lower cost. After five years of research, Cidaut has patented a new system with an improved heat-absorbing material, embedded with nanoparticles that allow for advanced absorption. Cidaut has also tweaked the fluid dynamics, the heat transfer system, and the panel's heat-retaining ability. The company that commissioned this research—which, because the panels are not yet on the market, does not wish to be named—already has the capacity to produce more than 100,000 panels a year.

This improvement of existing technology also propelled Cidaut's biomass project. Such waste-to-energy systems are



Supercritical CO_2 extraction tanks.

SUPERCRITICAL CARBON DIOXIDE

A faint herbal aroma wafts among the gargantuan metal tanks and clanking machinery. The scent comes from an Indian seed, neem, whose extracts are used as a biocide. And Altex, S.A., a company near Valencia, Spain, is using supercritical carbon dioxide to extract the oil from the seed.

Extracting compounds from agricultural products is common practice; decaffeinated coffee and cocoa butter from cocoa powder are two of the most familiar examples. But many solvents used to catalyze these separations contain harsh chemicals and may taint part of the original product, preventing its future use in food applications.

One promising solution to this problem is the use of supercritical carbon dioxide, which has been subjected to high pressure and temperatures such that its density becomes that of a liquid, while it retains the mobility of a gas. That flow, tweaked by temperature, pressure, and the addition of small amounts of other materials such as water, can be directed to latch onto specific types of molecules, pull them away from the rest of the material, and then deposit them elsewhere following a decrease in pressure. The use of supercritical carbon dioxide can, for instance, separate out cocoa butter and leave behind a pure cocoa powder residue. The carbon dioxide is then recovered and reused.

Engineers at the research center Ainia developed a system for optimizing supercritical carbon dioxide for food and developed methods for specific food products. The center has also spun this technology off and created the company (Altex, S.A.), which operates one of the largest facilities for supercritical carbon dioxide extraction in the world. Altex works with customers around the world, including France, the UK, and Australia, to develop systems to extract plant-based compounds, including cocoa powder, valerian root extract, and neem. One project involved developing a proprietary technique for a company interested in eliminating a chemical component in cork, to prevent cork from contaminating wine.

"Our flexibility means that we can offer these services to food and beverage companies, and also for cosmetics and pharmaceuticals," says Antonio Tornero, Altex general manager. "There is nothing we can do to damage the original materials."

PHOTO COURTESY OF CYNTHIA GRABER

not widely used today, says Merino, because the feedstocks—such as wood chips or agricultural waste— "have to be brought long distances to a [large] biomass facility, and so waste a lot of energy in the transportation." The biomass concept involves gassifying or burning the biomass and using the heat to generate steam for electricity. But there hasn't yet been an efficient, inexpensive small-scale model of a biomass facility available on the market.

So Cidaut engineers took advantage of their expertise in engines, and developed an efficient small-scale system that can make use of waste where it's generated and provide on-site power. Cidaut developed a combustion process that produces carbon monoxide, then coupled that with combustion motors adapted to the gas. "The resulting system is small and easy to transport—any type of trailer can be used—and it can be placed anywhere there's organic waste. It works at the efficiency and cost comparable to much larger systems," says Merino. They're in the process of finalizing this product for a wider market.

Another method of converting waste to energy relies on biogas, the production of methane from fermenting organic materials. Ainia, with extensive research capabilities in the food sector, set to improving the fuel side of the equation.

Agricultural centers have expressed interest and are starting to utilize methane, primarily from the decomposition of animal waste, to fuel electricity generation. But, as Ainia's research director Miguel Blasco points out, research on the appropriate recipes can lead to significantly higher production of methane from the same feedstocks. Scientists are evaluating the mix of feedstocks and simultaneously determining methods to control odor and produce an added-value compost.

In the laboratory, various blends of agricultural products are capped by bags to trap and evaluate the gasses emitted. "We're optimizing the product by taking cow manure, and adding other materials with higher levels of sugars, fats, and polysaccharides, that together generate more methane," says Blasco. They've tested the addition of not only other agricultural materials, but also urban food residue, and worked on pretreatments that could increase methane production. The system, Blasco explains, creates no waste, since the residue can be used as compost. Ainia has developed a bioreactor and generator pilot plant that is currently being tested in a nearby farm, in the town of Requena.

To prolong the life of wind power turbines, and to increase the environmental sustainability of the parts involved, Tekniker is developing new biolubricants while it creates monitoring systems to evaluate the quality and degradation of lubricants in the systems. "This will become increasingly important as systems move off-shore, or in new wave and current systems," explains Javier Laucirica, Tekniker's scientific director. "There are significant amounts of oils in these systems, and strong seas increase the risk of oil spillage. So developing bio-oils that can withstand salt and other ambient conditions is a key point for these systems."

> "In Europe, as you develop new products, there is also horizontal research on recycling."

Tekniker is also leveraging its decades of experience in precision manufacturing to work with solar power customers to increase the geometric accuracy of the mirrors that concentrate the sun's rays to a focal point. The efficiency of the system also depends on how well the tube at the focal point absorbs and contains the sun's heat, says Laucirica, so Tekniker is also working on projects to increase the capabilities of the tubes.

The Gaiker center builds on its plastics manufacturing expertise to develop new machinery and robotics for plastics separation and recycling. Gaiker has continued along the recycling and waste stream analysis research path, identifying and analyzing the components of ordinary household waste, electronics, and vehicle waste for potential separation and reuse; Gaiker researchers have created tools to help facilitate the waste separation process. As technology has hurtled along with the integration of new gadgets and materials, Gaiker has stayed one step ahead of the market in identifying the trends and the materials involved.

Now the center is working on recycling OLEDs (organic light-emitting diodes), which are thus far used in the screens of only a handful of products. "In Europe, as you develop new products, there is also horizontal research on recycling," says Salas. "You need to know what is going to happen when the product enters the waste stream, and what we can do with it."

ENTERTAINMENT

Toni Mateos, director of Barcelona Media's audio research line, sits down at a computer. With a few clicks, he pulls up a scene on a huge screen at the front of the room. An image of a lizard fills the screen. Sounds of minute movements, including the faint crackling of a twig, emanate from the two dozen speakers in the test facility. Suddenly, it begins to rain on screen. In the room, the sound emanates not from the screen, not from around the room, but from directly overhead, above the listeners' heads. This is no movie theater surround-sound: this sound transports viewers to the center of a tropical downpour.

This 3-D audio programming is a product of research at Barcelona Media, located in the heart of the city. 3-D sound has not yet reached anywhere near the penetration of 3-D visual



3-D virtual representation of section of Barcelona

imagery, in part because of challenges in both recording and broadcasting it, and in part because standardization of speakers and algorithms to translate signals to the speakers is lacking. So far, there are multiple systems for recording and broadcasting three-dimensional sound, and they need to match exactly.

To overcome this challenge, engineers at Barcelona Media are approaching the problem by recording not just the acoustic pressure of the sound waves, but other parameters, including the speed of the waves. They're simultaneously developing computer programs that can translate these signals into 3-D recordings for a variety of speaker systems, without knowing the configuration of the end broadcast.

The sound research team has also modified these 3-D sound systems to allow for a realistic sound experience within a virtual environment. For instance, a viewer may move among flamenco musicians on a screen; as the viewer moves past a guitar player, the trills of the guitar suddenly emanate from behind.

The center has also developed a 3-D virtual representation of the city of Barcelona for urban planners. Its users can navigate through the city and evaluate planned projects and their impact on the city, right down to noise and shadow impacts. They can also leave behind the public face of the city and descend beneath the buildings to travel among the cable fibers and gas conduits.

"This is a sector that's based on creativity," says Marta Ysern, director of special projects. "And in order to survive, you have to be successful–and that means that we must be constantly innovating."

PHOTO COURTESY OF BARCELONA MEDIA

RESOURCES

ICEX (Spanish Institute for Foreign Trade)
www.spainbusiness.com
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TO MARKET



VISUAL EFFECTS

3-D MOVIE CAMERA

MAKING 3-D films involves shooting scenes from two slightly different angles, a task that once required a 450-pound camera system moved by machinery. For the blockbuster *Avatar*, director James Cameron used a camera that could be carried, but it still weighed 50 pounds and had multiple parts. A new model weighs just seven pounds and is the first professional-quality camcorder to combine all the necessary components for 3-D filmmaking: lenses, camera head, and twin memory card recorder. The camera handles the tricky calibration process through a combination of user controls and automated systems. It could bring 3-D effects within reach of independent filmmakers for the first time.

Product: AG-3DA1 Full HD 3D Camcorder **Cost:** $21,000 **Availability:** Fall 2010
Source: www.panasonic.com **Company:** Panasonic Broadcast

COURTESY OF PANASONIC

MATERIALS

OLED PRODUCTS

The newest organic light-emitting diodes (OLEDs) are bigger, transparent, and able to emit purer white light.



BIGGER OLED TV

OLED DISPLAYS are very thin and render colors more vividly than other technologies. They also have a nearly 180° viewing angle and refresh nearly 1,000 times as fast as liquid-crystal displays. But they're tricky to make in large sizes. The largest OLED TV to reach market has a screen measuring 15 diagonal inches—beating an 11-inch model offered by Sony—and is just three millimeters thick.

Product: EL9500 LG 15-inch OLED television
Cost: About $2,750 **Availability:** May 2010 in Europe; summer in United States **Source:** www.lge.com **Company:** LG Electronics



GLOWING LIGHT DISCS

LIGHTING MAKER Osram is introducing its first white-light products using OLEDs. Though not as efficient as compact fluorescent bulbs or inorganic light-emitting diodes, the eight-centimeter round panel gives a diffuse glow and a true white that's comparable to that of incandescent bulbs. The appearance of its white doesn't change at different dimming levels, a problem with some earlier prototypes. The product is meant for places like museums and hotels; it's a bit costly for home use.

Product: Orbeos **Cost:** $325 **Availability:** Now for version shown (CDW-031); June for version with reflective surface (CMW-031) **Source:** www.osram-os.com **Company:** Osram Opto Semiconductors

SEE-THROUGH MP3 PLAYER

A HANDHELD media player is the first to sport a see-through active-matrix OLED touch screen. The device comes with 16 gigabytes of memory and supports all major audio and video formats. But its main selling point is that it lets you watch a video while also watching where you are going.

Product: IceTouch
Cost: To be announced
Availability: To be announced
Source: www.samsung.com
Company: Samsung



COURTESY OF LG (TV); OSRAM (LIGHT); SAMSUNG (ICETOUCH)

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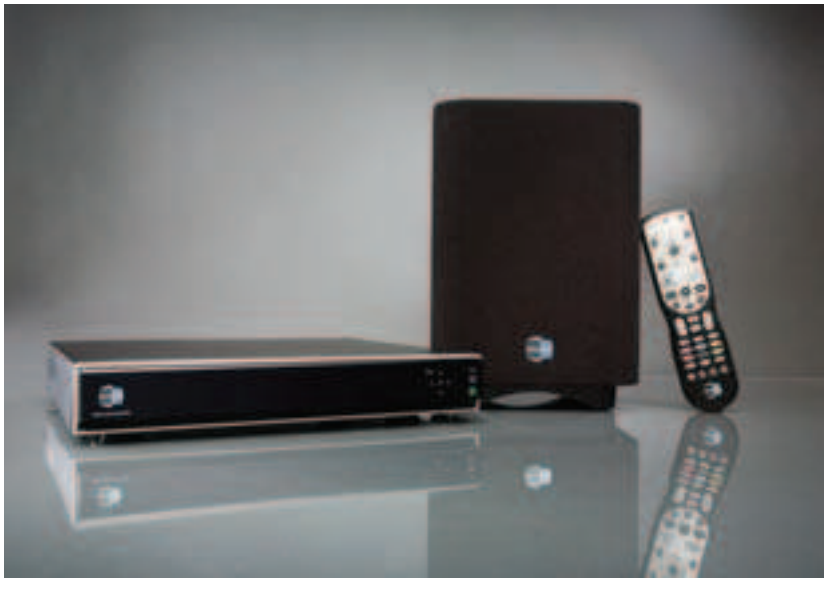


TRANSPORTATION

FAN PACK

THE FIRST practical jet-pack-like gadget to reach market might find its first applications among emergency personnel who need to reach remote areas. The device doesn't have actual jet engines; instead, it uses a gasoline engine to power two ducted fans. It flies for 30 minutes at up to 97 kilometers per hour. Users control pitch and roll with one hand and throttle and yaw with the other. A parachute reduces the chances of injury.

Product: Martin Jetpack
Cost: $100,000
Availability: 2011
Source: www.martinjetpack.com
Company: Martin Aircraft Company



MEDIA

ONE BOX TO RULE THEM ALL

A NEW set-top box grabs content from broadcast channels, cable stations, and the Web, making it easy to watch anything, anytime, from any source, on a home television. The system—which also requires a subscription service—suggests shows to users, drawing on stated preferences and past viewing habits to guide recommendations.

Product: Sezmi **Cost:** $299 for the system; $4.99 or $19.99 per month for service **Availability:** Now in Los Angeles; spring 2010 in other parts of the United States **Source:** www.sezmi.com **Company:** Sezmi

COURTESY OF MARTIN JETPACK (FAN PACK); SEZMI (BOX)



lead innovation

Technology Innovation for Intelligence Dominance

The National Reconnaissance Office **Director's Innovation Initiative (DII) Program** nurtures innovative concepts and creative ideas to transform intelligence to revolutionize systems and capabilities for future intelligence needs. The program funds the brightest minds, best ideas, and break through technology from individuals in industry, academia, national laboratories, and other U.S. government agencies. Log onto the DII website for proposal guidance, frequently asked questions, history, and BAA and GSSA requirements.

DII research funding supports cutting-edge scientific research in a high-risk, high-payoff environment.

http://dii5.westfields.net



DIAGNOSTICS

SELECTING EMBRYOS

DOCTORS who perform in vitro fertilization typically rely on a visual assessment of the embryos when deciding which ones to transfer into the uterus, but two-thirds of such embryos fail to implant. A new test analyzes the proteins and small-molecule metabolites in the fluid surrounding each embryo and compares the resulting metabolic profile with that of a healthy embryo. The test improves implantation rates up to 30 percent. That means doctors can transfer fewer embryos, reducing the chances of an undesired multiple pregnancy.

Product: ViaMetrics-E **Cost:** $30,000 to $50,000 for the testing system in the U.S. market. (Tests will not add appreciably to the typical cost of $12,000 to $15,000 for an IVF treatment.) **Availability:** Now in the U.K., Australia, Japan, Ireland, and Greece; seeking FDA approval in the U.S. **Source:** www.molecularbiometrics.com **Company:** Molecular Biometrics



ENERGY

FUEL-CELL POWER BOOST

A NEW FUEL CELL is 50 times as powerful as any other product that generates electricity from liquid methanol, thanks to improved catalyst and membrane technologies. The system can keep electric forklifts and other factory vehicles running for 16 hours. Compared with using electricity from coal-fired power plants to charge a battery pack, it reduces carbon emissions 66 percent.

Product: OorjaPac Model 1
Cost: $30,000
Availability: Summer 2010
Source: www.oorjaprotonics.com
Company: Oorja Protonics



NETWORKING

WIRELESS HOME THEATER

NETGEAR is commercializing a system that can send multiple jitter-free full-HD video streams wirelessly throughout a home. The kit has two wireless adapters; one links to an Internet router to capture Internet TV shows, and the other links to home theater devices such as Blu-ray players, Xbox 360s, and Internet TVs. The product achieves reliable transmission with technologies fairly new to the consumer market, including multiple-output antennas and dynamic digital beam-forming.

Product: High-Performance Wireless-N HD Home Theater Kit **Cost:** To be announced **Availability:** Fall 2010
Source: www.netgear.com/HDWiFi **Company:** Netgear

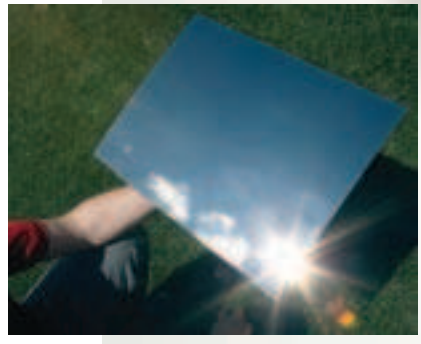
COURTESY OF MOLECULAR BIOMETRICS; ERIK PAWASSAR (FUEL CELL); COURTESY OF SEZMI (HDTV)


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RENEWABLE POWER

SOLAR COST CUTTER

A HIGHLY reflective thin film made of microlayers of silver and copper, protected by a polymer and backed with adhesive, could cut the cost of solar thermal power plants by hundreds of millions of dollars. In most such plants, glass mirrors concentrate heat from the sun to create steam that spins conventional turbines. The thin film—which replaces those mirrors—reflects more light, increasing power output.



Product: 3M Mirror Film
Cost: $20 per square meter
Availability: Spring 2010
Source: www.3m.com
Company: 3M



MICROPROJECTORS

PROJECTED MULTITOUCH SCREEN

THIS INTERACTIVE projector transforms any flat surface into a multitouch screen. When a person's fingers touch the display, infrared sensors detect the motion and allow the same kinds of interactions that are possible on, say, an iPhone. The product is initially being made available to industrial partners for commercial applications such as interactive displays in retail or educational settings.

Product: Light Touch **Cost:** Not available **Availability:** Now to industrial partners; first products from partners to reach market in late 2010 **Source:** www.lightblueoptics.com
Company: Light Blue Optics

COURTESY OF 3M (FILM); LIGHT BLUE OPTICS (PROJECTOR)



Introducing
Server Room in a Box

APC integrated cooling future-proofs your IT room without breaking the bank.

Is your server room a barrier to adopting new technologies?

Consolidation, virtualization, network convergence, blade servers—these new technologies improve efficiency, cut costs, and allow you to "do more with less." But they also bring high-density power, cooling, and management challenges that server rooms were never designed to handle. You're relying on guesswork, depending on building air conditioning, or improvising remedies. So how can you increase the level of reliability and control in your server room without spending a fortune?

Introducing the APC by Schneider Electric total server room solution

Now you can get power, cooling, monitoring, and management components that easily deploy together as a complete, integrated solution. Everything has been pre-engineered to work together and integrate seamlessly with your existing equipment. Just slide this proven, plug-and-play solution into most existing spaces—there's no need for confusing cooling configurations or expensive mechanical re-engineering. The modular, "pay as you grow" design lets you be 100 percent confident that your server room will keep pace with ever-changing demands.

Future-proof your server room easily, cost-effectively

APC takes the hassle out of configuring server rooms. Self-contained InRow cooling units, high-density NetShelter enclosures, and the APC rack air containment system combine to create a proper IT ecosystem in almost any surrounding. Rack-level monitoring sensors, intelligent controls built into the cooling unit, and integrated management software provide complete remote control and unprecedented visibility into the entire system. Simply add power protection (like undisputed best-in-class Smart-UPS or Symmetra units) and you have a total solution for today, tomorrow, and beyond.

APC rack-based cooling draws in hot air from the rear, at its source, and then sends conditioned air out the front, ready to be used by adjoining racks.

If you have dedicated IT space . . .

Get pre-validated, high-density cooling as a single offering.

APC InRow SC System combines an InRow SC precision cooling unit (up to 7kW capacity), NetShelter SX rack enclosure, and rack air containment system, for a limited time, at a specially discounted price.



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Follow the Flow

THE TRAIL OF U.S. ENERGY—WHAT WE USE, AND HOW WE WASTE IT

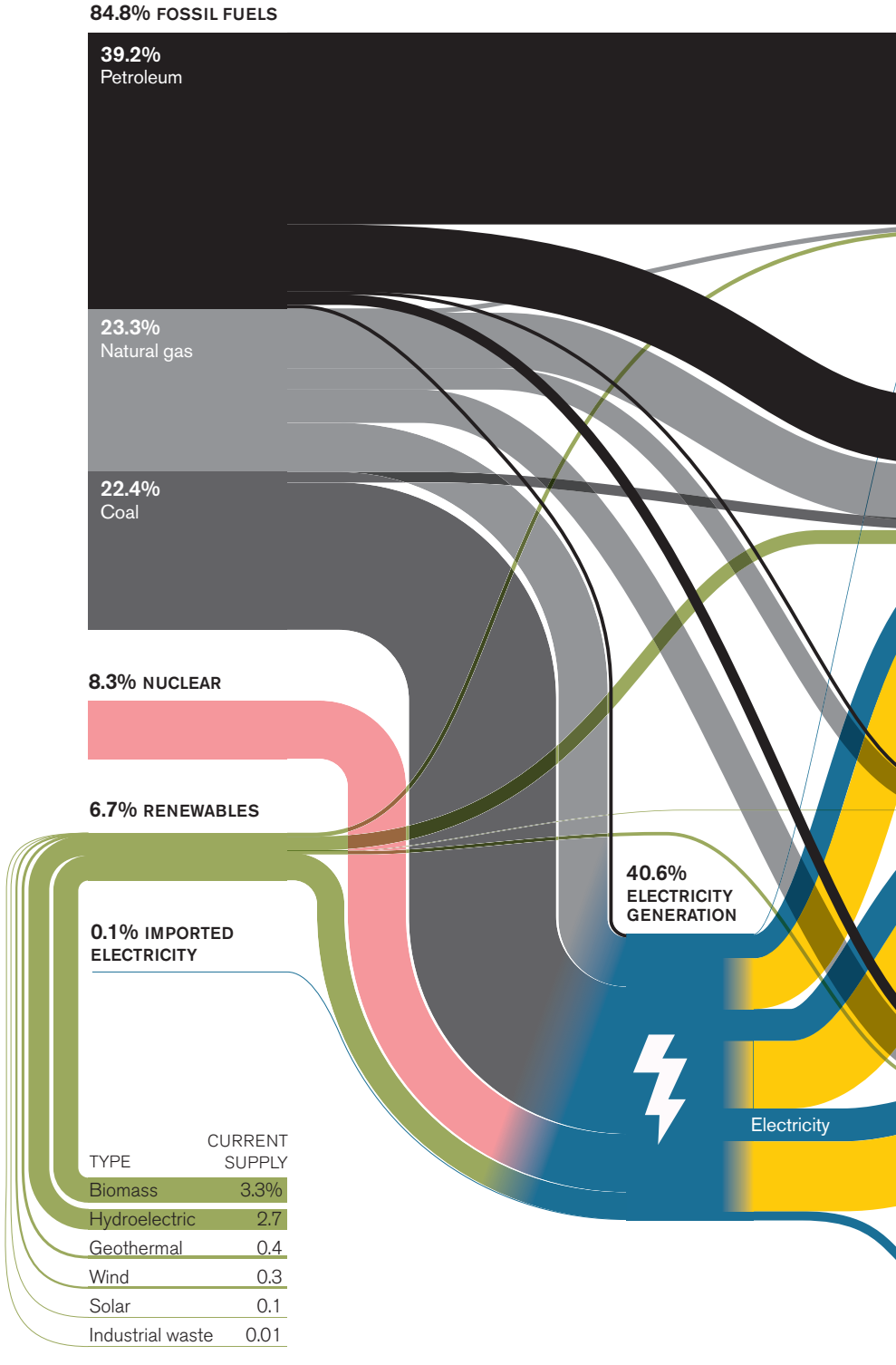
If you tried to get an all-embracing view of energy use in the United States, it wouldn't take long for your eyes to go blurry. The Energy Information Administration and other sources release reams of data almost constantly. That's good if you want to look at minute detail, but not so good if you want the big picture.

Based on a version originally created by researcher David Bassett for the Woodrow Wilson Center, this energy flow map reveals the energy sources we draw from, the ways we use that energy, and the ways we waste it. Two elements are perhaps most striking: at bottom left, the relatively paltry contribution of renewables; and at far right, the staggering amount of energy lost as heat. On its own, this lost energy could satisfy the total demands of an industrialized nation like Japan or Germany.

Bassett created his first map of this kind in December 1990, while working in the pollution prevention division of the U.S. Environmental Protection Agency. When asked to update it to illuminate the current debate over energy policy, he jumped at the chance—but was dismayed when he compared the results with what he'd found two decades ago. "Aside from an increase in scale, they look much the same," he said. "It's sobering to realize how little we've been able to do to put this lost heat to use." *—Matt Mahoney*

FUEL SUPPLY

Fossil fuels continue to satisfy nearly all of the United States' energy demands. The potential for renewables to replace those fuels is still mostly unrealized.

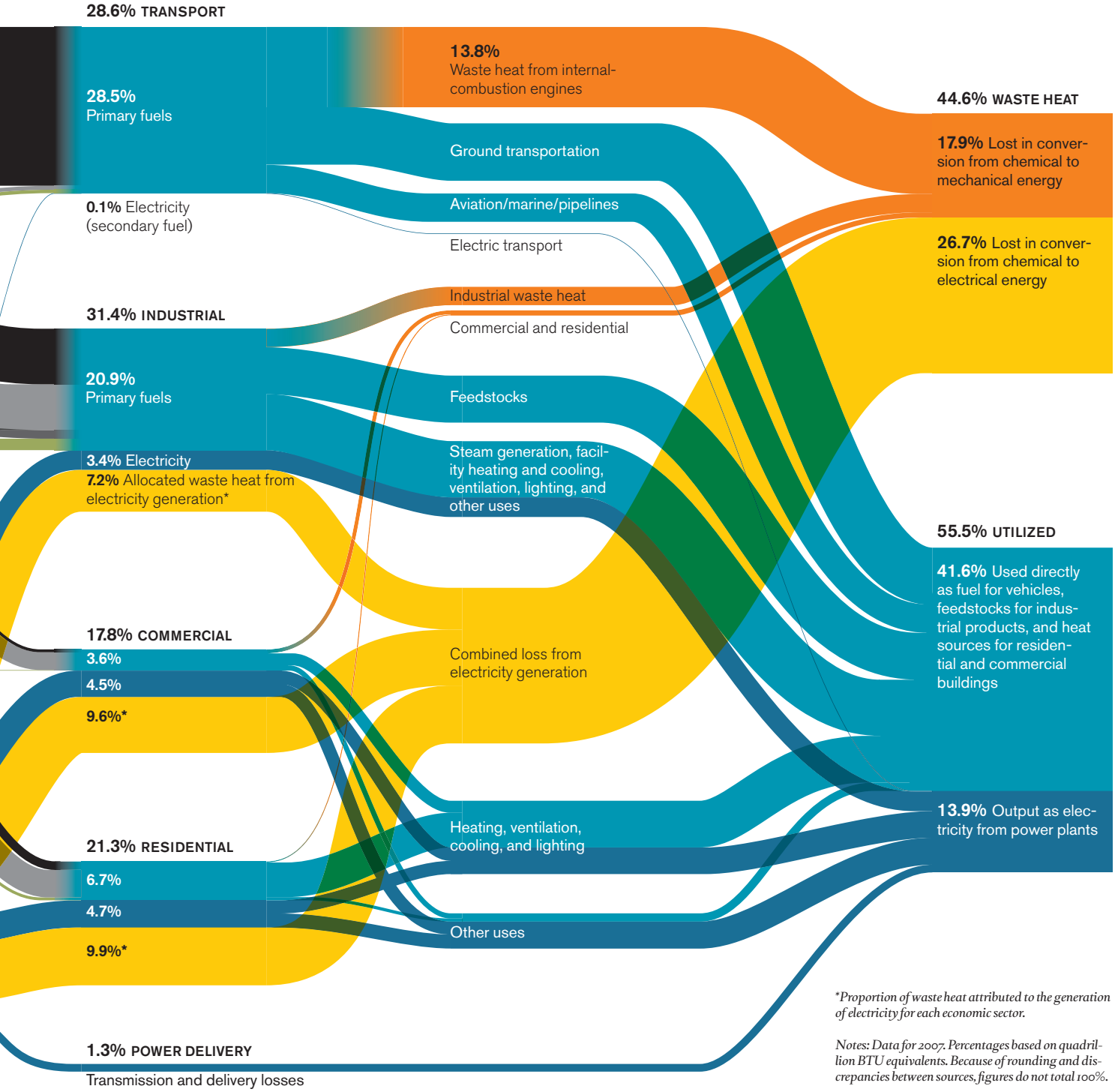


SECTOR DEMAND AND END USES

Nearly half of the nation's primary fuel supply is used to generate electricity. The rest is used to power vehicles and heat buildings, and as feedstocks for the chemical industry.

WINS AND LOSSES

Most heat loss occurs during electricity generation, but a lot is also lost in internal-combustion engines. Thermoelectric devices could eventually be used to convert some of that waste heat into electricity.



Proportion of waste heat attributed to the generation of electricity for each economic sector.

Notes: Data for 2007. Percentages based on quadrillion BTU equivalents. Because of rounding and discrepancies between sources, figures do not total 100%.

Sources: DOE Energy Information Administration. Based on chart prepared by David Bassett for the Woodrow Wilson International Center for Scholars and the Environmental Law Institute.

Information graphic by TOMMY MCCALL *and* DAVID BASSETT

Q&A

PAUL OTELLINI

Is the U.S. losing its competitive edge? Intel's boss thinks so.

As CEO of Intel, Paul Otellini knows a lot about the value of investments. And these days he's worried that the United States, after a decade of neglecting support for education, research, and digital infrastructure, is falling behind much of the world in its ability to compete economically and technologically.

Last year, during some of the grimmest days of the recession, Otellini announced that Intel would spend $7 billion to build fabrication plants in Oregon, New Mexico, and Arizona. While the move was meant to create manufacturing capacity for its new 32-nanometer chips, the timing, which came as Congress debated President Obama's stimulus bill, was also meant to signal its willingness to invest in the United States. This February, Otellini announced that Intel and a group of venture capital firms would supply $3.5 billion to U.S.-based technology startups over the next 18 to 24 months; a related initiative committed Intel and other high-tech companies to doubling their hiring of U.S. college graduates in 2010.

Fretting over U.S. competitiveness is nothing new: such concerns seem to make headlines every few years, peaking during poor economic times. So *Technology Review* editor David Rotman asked the Intel CEO why he is worried *now*.

TR: Why does it matter where innovation comes from? After all, about 75 percent of your revenues are from outside the U.S.

Otellini: [To us] as a global company, it probably doesn't matter. And as a multinational corporation, we have the ability to hire people from anywhere on earth. But there are still some fundamental concerns. I think that America is the best place in the world for innovation when it is done right. Historically, the infrastructure, capital markets, acceptance of failure, and the willingness to try again are uniquely American.

What's at stake for the U.S.?

As a country the issue is: are we going to be prepared for the industries of the 21st century, which are fundamentally knowledge-based industries? The alternative is to go back to 19th-century industries and get back to [manufacturing] steel and those kinds of things, but then you have to do it at costs that are comparable with the lowest costs in the world. That would require a reset of the standard of living, and most Americans are not willing to do that. If you want to maintain our standard of living, you need to adapt the workforce for the jobs of the future.

Do you see signs of this loss of competitiveness already?

You can measure the gradual erosion with something as straightforward as how our kids are doing in math and science. It's clear the best of the best coming out of our schools are world class. It is the average that I'm concerned about.

Has this begun affecting the U.S. economy?

It is so hard to tell. If we didn't have this giant recession, you might be able to measure [the effect] more accurately. But you can surmise that if the quality of skills of the workforce is eroding, it's a huge productivity loss.

What government policies would help?

Governments are best positioned to fund basic research. But there's been a decade-long erosion in the amount of that funding. It's now on a path to grow, and eventually the goal is to double it. But it takes a long time to do that. Secondly, we would like to see the R&D tax credit made permanent and returned to levels that are competitive with the rest of the world. Lastly, we have corporate tax rates that today are the second highest in the industrialized world.

Aren't there dangers when governments get involved in supporting innovation?

One potential pitfall is government picking industries and technologies. The job of government is to fund basic research and let scientists do their work and let the innovation fall where it may. I just think there has been insufficient funding, and we need to get it back to levels that are much more consistent with our historical norms.

Investing in startups is what venture capitalists are *supposed* to be doing. Why did they need encouragement?

Yes, it is their business, but the narrowness of the focus [on clean tech and high tech] and the narrowness of the investment period was also important. We wanted to show [startup companies] that the venture capital industry was open for business.

One of your recent speeches was titled "Reinventing America's Economic Future." What did you mean?

The fifty-thousand-foot view is, it's all about competitiveness. It is something that, as a country, we too often take for granted. We take for granted that capital will flow in, we take for granted that we will have the best workforce in the world, we take for granted that capital formation is there, that startups can have an exit through the IPO [initial public offering] market. None [of that] is to be taken for granted anymore. It was nurtured over 30 to 40 years, and for a variety of reasons it has either atrophied or been constrained. If we refocus our energies on competitiveness as a country, then other good things accrue: capital accrues, jobs accrue, investments accrue. It's really a recipe for what makes nations prosperous. TR

Photograph by GABRIELA HASBUN



PHOTO ESSAY

China Cleans Up

In 2006, China passed the United States as the world's top emitter of greenhouse gases; last year it exceeded U.S. investment in clean energy for the first time, with a total of $34.6 billion. Driving that investment are air pollution, which has reached choking levels in Chinese cities, and a strong desire to meet a voracious appetite for energy through domestic sources. Not only is the country adding nuclear, hydroelectric, wind, and solar power at an unrivaled pace, but it's fast becoming a proving ground for next-generation energy technologies that have stalled elsewhere.

By PETER FAIRLEY



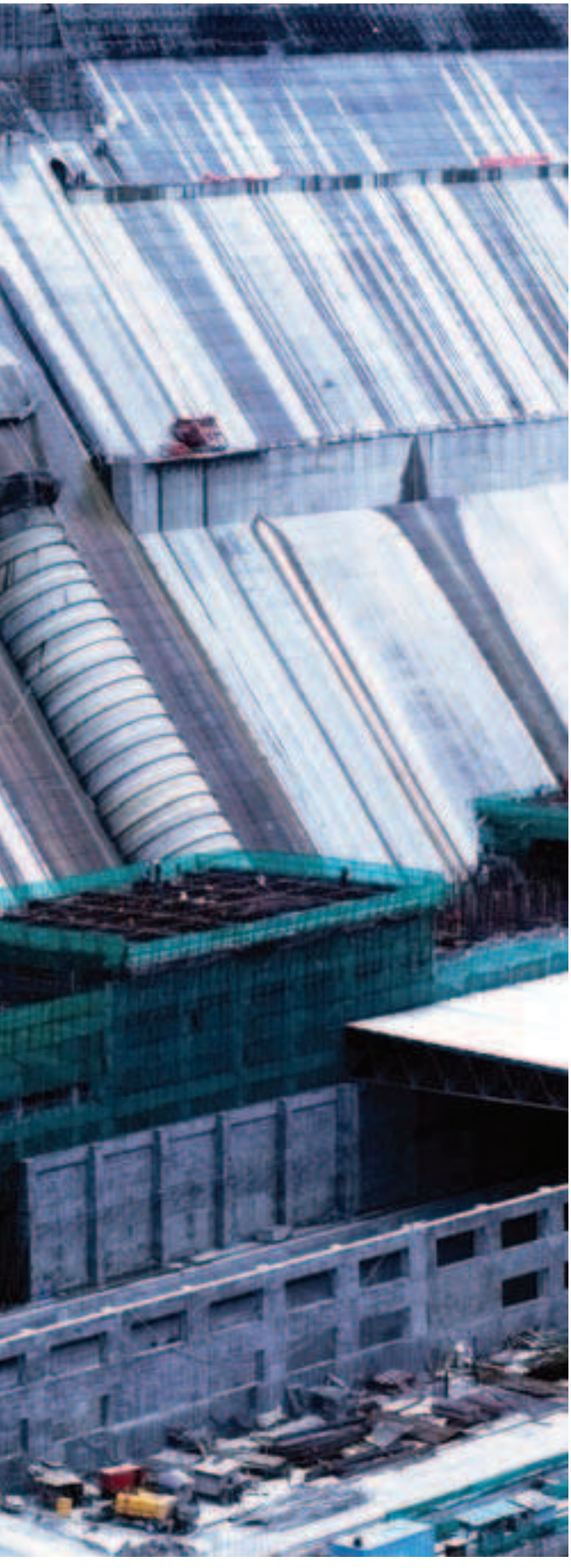
ZHENG SHUAI/CHINAFOTOPRESS/GETTY IMAGES



China has 22 nuclear reactors under construction, with a combined capacity of 23 gigawatts. Two-thirds of these, including this one at Fuqing on China's southeastern coast, use a homegrown design based on France's existing light-water reactors. Li Ganjie, director of China's National Nuclear Safety Administration, recently warned that "overrapid expansions" could diminish reactor quality and safety.



SIEMENS AG



A massive and controversial hydropower buildout is under way in western China. The Jinanqiao hydroelectric dam (at left), nearing completion, is one of a dozen installed or under construction on the Jinsha River. These dams were conceived partly as a trap to keep the "golden sands" for which the Jinsha is named from silting up the world's largest hydropower plant, the Three Gorges Dam, which sits downstream on the Yangtze. China is now building lines carrying direct current at 800 kilovolts and alternating current at 1,000 kilovolts—both world firsts—to pump that power to cities and manufacturing hubs in the east. ABB and Siemens provided the components—such as the toroids (below), which smooth out power blips. Plans call for a total of nine 800-kilovolt lines in China by 2020 and some $300 billion worth of grid upgrades through 2015.





The angled protrusions seen atop buildings in Fuyang City are solar collectors, a technology that provides hot water for about one in 10 Chinese residents. The Chinese government predicts that at least 150 million square meters of the heat-absorbing glass vacuum tubes will adorn rooftops by the end of this year. Himin Solar Energy is China's largest manufacturer of these tubes (right). China also boasts the world's largest manufacturer of crystalline silicon photovoltaics: Wuxi-based Suntech Power. Recently approved subsidies are stimulating the country's first utility-scale solar-power projects.





TU CHUN/IMAGINECHINA VIA AP IMAGES; NELSON CHING/BLOOMBERG VIA GETTY IMAGES



In February, Beijing-based Sinovel Wind erected a 34th wind turbine beside Shanghai's 32.5-kilometer Donghai Bridge, completing the first offshore wind farm outside Europe. The three-megawatt turbines will generate enough power altogether to meet the needs of more than 200,000 Shanghai households, according to the company. China has doubled its installed wind-power capacity every year for the past five years, and last year it supplanted the United States as the world's largest market for wind power.

SINOVEL



CHINATOPIX/AP



US-CHINA ENERGY CENTER, WEST VIRGINIA UNIVERSITY

Coal still meets 70 percent of China's energy needs, but the country claims to have shut down 60 gigawatts' worth of inefficient coal-fired plants since 2005. Among them is the one shown at left, which was demolished in Henan province last year. China is also poised to take the lead in deploying carbon capture and storage (CCS) technology on a large scale. The gasifiers that China uses to turn coal into chemicals and fuel emit a pure stream of carbon dioxide that is cheap to capture, providing "an excellent opportunity to move CCS forward globally," says Sarah Forbes of the World Resources Institute in Washington, DC. Shenhua Group, China's top coal producer, hopes to launch the country's first carbon storage project this year at its 24,000-barrel-per-day synthetic-diesel plant in Inner Mongolia (below).



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WHAT'S NEXT.

Join us on Wednesday, June 2nd, to honor some of New England's most innovative technologies and companies!

7th Annual MITX Technology Awards
Celebrating the Most Innovative Technology Accomplishments in New England

EVENT DETAILS:

Award Ceremony: **June 2, 2010 | 6:00pm - 8:30pm**

Location: **Boston Marriott Copley Place**

This show provides you a great opportunity to learn about the hottest new technologies out there and meet the brain trust behind them. Everything from the Segway to 'Guitar Hero' (the only video game ever embraced by the likes of Van Halen, the Beatles and local band Aerosmith) has been developed right here in New England — how can you afford to miss this preview of 'What's Next?'

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Congratulations to our finalists!

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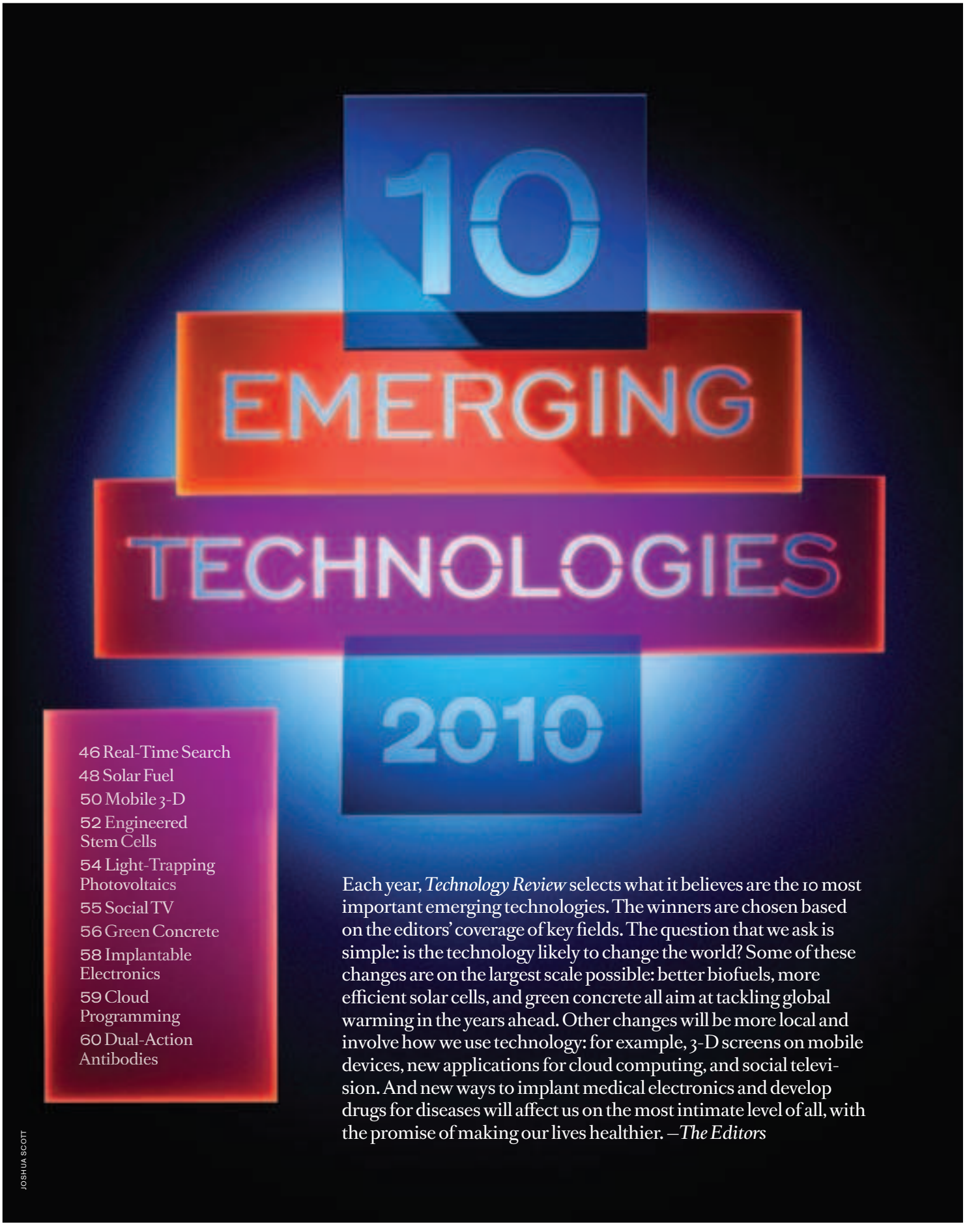
About MITX

MITX is about all things digital, about what's next for the Internet and how it impacts the marketing and business worlds. We are passionate about creating opportunities for individuals and businesses to connect, grow, and thrive. We are committed to showcasing the ideas, the innovations and the contributions that are fueling a thriving and integral industry in New England and throughout the world. If you want to be part of What's Next, join MITX.

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46 Real-Time Search
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50 Mobile 3-D
52 Engineered Stem Cells
54 Light-Trapping Photovoltaics
55 Social TV
56 Green Concrete
58 Implantable Electronics
59 Cloud Programming
60 Dual-Action Antibodies

Each year, *Technology Review* selects what it believes are the 10 most important emerging technologies. The winners are chosen based on the editors' coverage of key fields. The question that we ask is simple: is the technology likely to change the world? Some of these changes are on the largest scale possible: better biofuels, more efficient solar cells, and green concrete all aim at tackling global warming in the years ahead. Other changes will be more local and involve how we use technology: for example, 3-D screens on mobile devices, new applications for cloud computing, and social television. And new ways to implant medical electronics and develop drugs for diseases will affect us on the most intimate level of all, with the promise of making our lives healthier. —*The Editors*

JOSHUA SCOTT

10

Social networking is changing the way we find information
Real-Time Search

How do you parse a tweet? Five years ago, that question would have been gibberish. Today, it's perfectly sensible, and it's at the front of Amit Singhal's mind. Singhal is leading Google's quest to incorporate new data into search results in real time by tracking and ranking updates to online content—particularly the thousands of messages that course through social networks every second.

Real-time search is a response to a fundamental shift in the way people use the Web. People used to visit a page, click a link, and visit another page. Now they spend a lot of time monitoring streams of data—tweets, status updates, headlines—from services like Facebook and Twitter, as well as from blogs and news outlets.

Ephemeral info-nuggets are the Web's new currency, and sifting through them for useful information is a challenge for search engines. Its most daunting aspect, according to Singhal, is not collecting the data. Facebook and Twitter are happy to sell access to their data feeds—or "fire hoses," as they call them—directly to search providers; the information pours straight into Google's computers.

What's really hard about real-time search is figuring out the meaning and value of those fleeting bits of information. The challenge goes beyond filtering out spam, though that's an important part of it. People who search real-time data want the same quality, authority, and relevance that they expect when they perform traditional Web searches. Nobody wants to drink straight from a fire hose.

Google dominates traditional search by meticulously tracking links to a page and other signals of its value as they accumulate over time. But for real-time search, this doesn't work. Social-networking messages can lose their value within minutes of being written. Google has to gauge their worth in seconds, or even microseconds.

Google is notoriously tight-lipped about its search algorithms, but Singhal explains a few of the variables the company uses to analyze what he calls "chatter." Some are straightforward. A Twitter user who attracts many followers, and whose tweets are often "retweeted" by other users, can generally be assumed to have more authority. Similarly, Facebook users gain authority as their friends multiply, particularly if those friends also have many friends.

Other signals are more subtle. A sudden spike in the prevalence of a word in a message stream—*earthquake*, say—may indicate an important event. If a message on a commonly discussed topic includes unusual phrasing, that may signal new information or a fresh insight. Google, says Singhal, continuously scans for shifts in language and other deviations from predicted behavior.

The company is also working to connect message content to the geolocation data that's transmitted by smart phones and other mobile computers, or broadcast through services like Foursquare. The location of someone sending a message can matter a great deal. If you know that a person tweeting about an earthquake is close to the epicenter, chances are those tweets will be more valuable than those of someone hundreds of miles away.

Singhal's view of real-time search is very much in line with Google's strategy: distilling from a welter of data the few pieces of content that are most relevant to an individual searcher at a particular point in time. Other search providers, including Google's arch rival, Microsoft, are taking a more radical view.

Sean Suchter, who runs Microsoft's Search Technology Center in Mountain View, CA, doesn't like the term *real-time search*, which he considers too limiting. He thinks Microsoft's Bing search engine should not just filter data flowing from social networks but become an extension of them.

Ultimately, says Suchter, one-on-one conversations will take place within Bing, triggered by the keywords people enter. Real-time search, he predicts, will be so different from what came before that it will erase Google's long-standing advantages. "History doesn't matter here," he says. After a pause, he adds, "We're going to wipe the floor with them."

Amit Singhal has heard such threats before, and so far they haven't amounted to much. But even he admits that real-time search comes as close to marking "a radical break" in the history of search as anything he's seen. Keeping Google on top in the age of chatter may prove to be Singhal's toughest test. —*Nicholas Carr*

AMIT SINGHAL
(Google) Real-time search means people will be able to track rapidly changing events

OTHERS WORKING ON REAL-TIME SEARCH
Sean Suchter, Microsoft Search Technology Center, Mountain View, CA
OneRiot, Boulder, CO
Sency, Santa Monica, CA

To watch video reports on these technologies, take a snapshot of this code with software available at www.neoreader.com,or visit **www.technologyreview.com/tr10.**

TOBY BURDITT



THE REAL-TIME MAN
Google's Amit Singhal is mining social networks to generate up-to-the-second search results.



FUEL FOR THE FUTURE
Joule Biotechnologies' genetically engineered microörganisms can turn sunlight into ethanol or diesel.



BOB O'CONNOR

Designing the perfect renewable fuel
Solar Fuel

When Noubar Afeyan, the CEO of Flagship Ventures in Cambridge, MA, set out to invent the ideal renewable fuel, he decided to eliminate the middleman. Biofuels ultimately come from carbon dioxide and water, so why persist in making them from biomass—corn or switchgrass or algae? "What we wanted to know," Afeyan says, "is could we engineer a system that could convert carbon dioxide directly into any fuel that we wanted?"

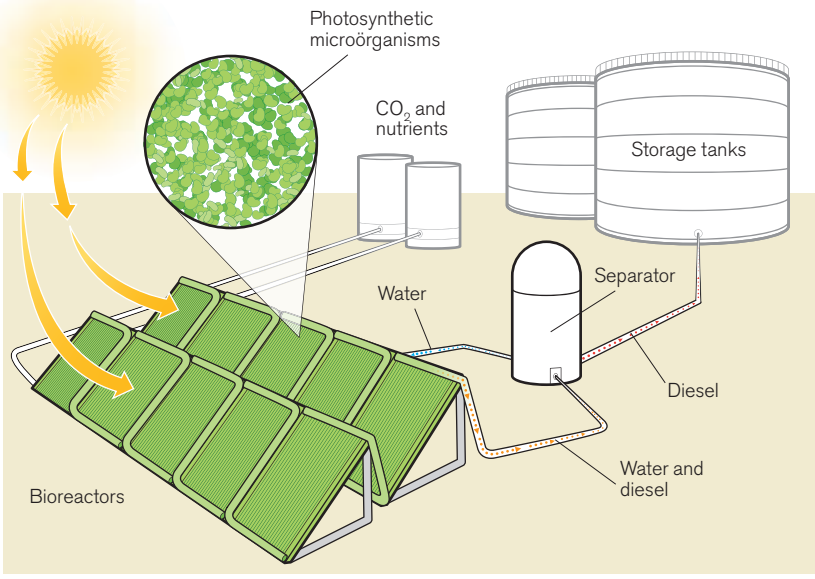
The answer seems to be yes, according to Joule Biotechnologies, the company that Afeyan founded (also in Cambridge) to design this new fuel. By manipulating and designing genes, Joule has created photosynthetic microörganisms that use sunlight to efficiently convert carbon dioxide into ethanol or diesel—the first time this has ever been done, the company says. Joule grows the microbes in photobioreactors that need no fresh water and occupy only a fraction of the land needed for biomass-based approaches. The creatures secrete fuel continuously, so it's easy to collect. Lab tests and small trials lead Afeyan to estimate that the process will yield 100 times as much fuel per hectare as fermenting corn to produce ethanol, and 10 times as much as making it from sources such as agricultural waste. He says costs could be competitive with those of fossil fuels.

If Afeyan is right, biofuels could become an alternative to petroleum on a much broader scale than has ever seemed possible. The supply of conventional biofuels, such as those made from corn, is constrained by the vast amount of water and agricultural land needed to grow the plants they're made from. And while advanced biofuels require less water and don't need high-quality land, their potential is limited by the expensive, multistep processes needed to make them. As a result, the International Energy Agency estimates that in 2050, biodiesel and ethanol will meet only 26 percent of world demand for transportation fuel.

NOUBAR AFEYAN
(Joule Biotechnologies) Solar fuels are produced directly by photosynthetic microbes fed carbon dioxide

OTHERS WORKING ON SOLAR FUELS
Synthetic Genomics, La Jolla, CA
BioCee, Minneapolis, MN
University of Minnesota BioTechnology Institute, St. Paul, MN

10



OIL FARM Arrays of bioreactors filled with Joule Biotechnologies' microörganisms absorb sunlight. Supplied with carbon dioxide and nutrients, the organisms use photosynthesis to produce diesel. As they secrete it, the diesel fraction circulates to a separator that extracts the fuel and sends it to storage tanks.

Joule's bioengineers have equipped their microörganisms with a genetic switch that limits growth. The scientists allow them to multiply for only a couple of days before flipping that switch to divert the organisms' energy from growth into fuel production. While other companies try to grow as much biomass as possible, Afeyan says, "I want to make as little biomass as I can." In retrospect, the approach might seem obvious. Indeed, the startup Synthetic Genomics and an academic group at the BioTechnology Institute at the University of Minnesota are also working on making fuels directly from carbon dioxide. Joule hopes to succeed by developing both its organisms and its photobioreactor from scratch, so that they work perfectly together.

Still, it's a risky strategy, since it departs from established processes. Usually, a startup sets out determined to do something novel, says James Collins, a professor of biomedical engineering at Boston University and a member of Joule's scientific advisory board, "and it falls quickly back on trying to find something that works ... an old thing that's been well established." Afeyan, however, has pushed the company to stay innovative. This summer, it will move beyond lab-scale tinkering; an outdoor pilot plant is currently under construction in Leander, TX.

As both a venture capitalist and a technologist—he received his PhD in chemical engineering from MIT in 1987—Afeyan is keenly aware of the challenges in demonstrating that a novel process can operate economically and make fuel in large volumes. To minimize the financial risks, he steered Joule toward a modular process that doesn't require large and expensive demonstration plants.

"I'm not saying it's easy or around the corner, because I've done this for a long time," Afeyan says. But he does believe that Joule is onto something big: a renewable fuel that could compete with fossil fuels on both cost and scale. He says, "We have the elements of a potentially transformative technology." *—Kevin Bullis*

Smart phones will take 3-D mainstream

Mobile 3-D

The Samsung B710 phone looks like a typical smart phone, but something unexpected happens when the screen is moved from a vertical to a horizontal orientation: the image jumps from 2-D to 3-D. The technology that produces this perception of depth is the work of Julien Flack, CTO of Dynamic Digital Depth, who has spent more than a decade perfecting software that can convert 2-D content to 3-D in real time. It could help solve the biggest problem with 3-D: the need for special glasses that deliver a separate image to each eye.

Flack's software synthesizes 3-D scenes from existing 2-D video by estimating the depth of objects using various cues; a band of sky at the top of a frame probably belongs in the far background, for example. It then creates pairs of slightly different images that the viewer's brain combines to produce the sensation of depth.

JULIEN FLACK
(Dynamic Digital Depth) Mobile 3-D could spark new computing applications and interfaces

OTHERS WORKING ON MOBILE 3-D
3M, St. Paul, MN
Nintendo, Kyoto, Japan
Nvidia, Santa Clara, CA
N4D, Atlanta, GA

The technology can be used with the much-hyped 3-D televisions announced in January (which require glasses), but its biggest impact will be as a way to create content for mobile devices with autostereoscopic 3-D displays, which work by directing light to deliver different versions of an image directly to each of a viewer's eyes. The effect works best over a narrow range of viewing angles, so it is ill suited to television or cinema screens.

BROWN BIRD DESIGN



3-D ON THE GO Released in South Korea in March, Samsung's W960 mobile phone comes with 3-D video content, generated by Dynamic Digital Depth, that can be viewed without special glasses. Dynamic Digital Depth expects that its software to convert 2-D games to 3-D on the fly will be built into phones within the next two years.

BRYAN CHRISTIE DESIGN

But phones are generally used by one person at a time and are easily held at the optimum angle. That's why mobile multimedia devices are likely to win the race to bring 3-D into the mainstream.

Powered by Flack's software, Dynamic Digital Depth has become an early leader in mobile 3-D. The software was built into the B710, which Samsung released in South Korea in 2007, and Samsung has licensed 3-D content generated by Dynamic Digital Depth for its latest 3-D phone, the W960, released in March. Research firm DisplaySearch recently predicted that by 2018 there will be 71 million such devices worldwide.

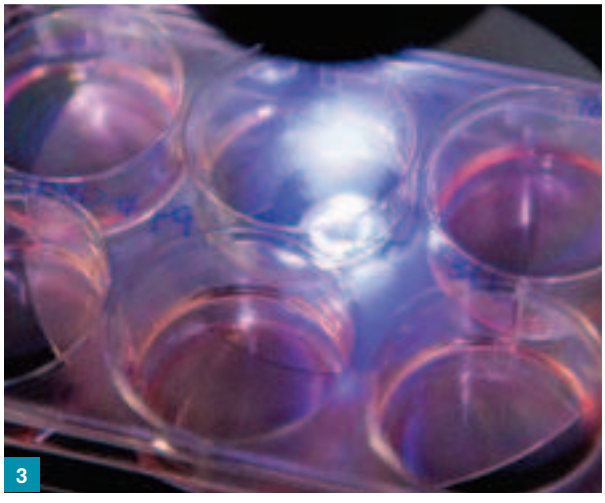
The most exciting area for Flack right now is games. Hundreds of games actually simulate 3-D spaces internally to handle mechanics such as the path of a missile, and then convert those 3-D spaces into 2-D to display to the player. With his technology, he says, the 3-D geometry "available inside the game itself" can be made accessible to the display. DDD has already released software that converts games to 3-D on PCs and expects to have similar software running on mobile devices in the next year or two.

It's applications like mobile games and video that will drive the widespread adoption of 3-D screens. And that, in turn, could lay the groundwork for a new generation of surprising interfaces and applications, just as large 2-D screens on mobile devices spawned developments such as touch-based interfaces and augmented reality. *—Annalee Newitz*

10


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Mimicking human disease in a dish
Engineered Stem Cells

The small plastic vial in James Thomson's hand contains more than 1.5 billion carefully coddled heart cells grown at Cellular Dynamics, a startup based in Madison, WI. They are derived from a new type of stem cell that Thomson, a cofounder of the company, hopes will improve our models of human diseases and transform the way drugs are developed and tested.

Thomson, director of regenerative biology at the Morgridge Institute at the University of Wisconsin, first isolated human embryonic stem cells in 1998. Isolating these cells, which are capable of maturing into any other type of cell, marked a landmark in biology—but a controversial one, since the process destroys a human embryo. A decade later, Thomson and Junying Yu, then a Wisconsin postdoc, reached another milestone: they developed a way to make stem cells from adult cells by adding just four genes that are normally active only in embryos. (Japanese researcher Shinya Yamanaka simultaneously published a similar approach.) Dubbed induced pluripotent stem cells (iPS cells), they have the two defining characteristics of embryonic stem cells: they can reproduce themselves many times over, and they can develop into any cell type in the human body. Because no human embryos are used to create them, iPS cells solve two problems that had long plagued researchers: political protest and shortages of material.

Much of the excitement over iPS cells, and stem cells in general, arises from the possibility that they could replace damaged or diseased tissue. But Thomson thinks their most important contribution will be to provide an unprecedented window on human development and disease. Scientists can create stem cells from the adult cells of people with different disorders, such as diabetes, and induce them to differentiate into the types of cells damaged by the disease. This could allow researchers to watch the disease as it unfolds and trace the molecular processes that have gone awry.

In the nearer term, iPS cells may revolutionize toxicity testing for drugs. The cells are "the first unlimited source of any type of human tissue," says Thomson, who founded Cellular Dynamics to put stem cells to practical use. The company sells heart muscle cells derived from its iPS cells to pharmaceutical giants such as Roche, which are using them to screen experimental drugs for harmful

JAMES THOMPSON
(Cellular Dynamics) Engineered stem cells could revolutionize drug discovery

OTHERS WORKING ON ENGINEERED STEM CELLS
Fate Therapeutics, San Diego, CA
iPierian, South San Francisco, CA
George Daley, Children's Hospital Boston, Boston, MA
Shinya Yamanaka, Kyoto University, Kyoto, Japan

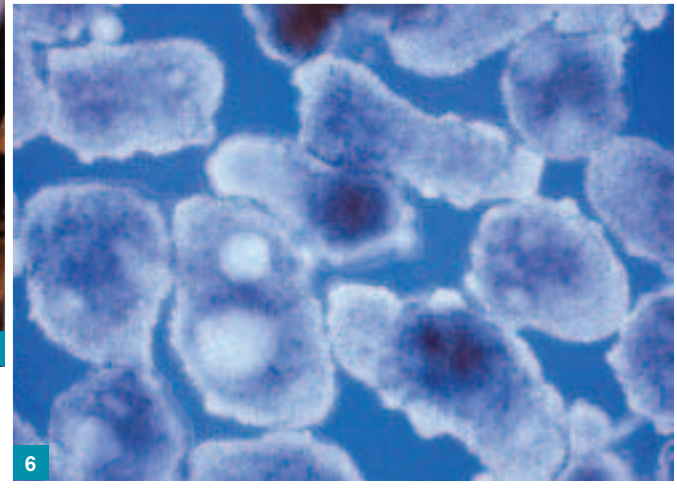
KEVIN MIYAZAKI



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side effects. Thomson hopes those cells will help uncover problems early in the drug development process, saving billions of dollars on research and testing. For instance, since the iPS-derived heart cells will beat in a dish, scientists should be able to detect which drugs alter the heart's rhythm. Scientists can also use the cells to study how the heart functions at a molecular level. And the company is developing other cell types, including brain and liver cells. The latter are of particular interest to pharmaceutical researchers, since drug toxicity often shows up in the liver. "Having a model that would predict toxicity before going into humans is incredibly valuable," says Chris Parker, vice president and chief commercial officer of Cellular Dynamics.

By generating iPS cells from people with diverse ethnic backgrounds and genetic conditions, and from those who have reacted poorly to certain drugs, scientists can also gain a better picture of how compounds will affect different people. Thomson and others have already created iPS cells from people with ALS, Down syndrome, and spinal muscular atrophy, among other disorders. While it's not yet clear how well those cells reflect the specific diseases, early research is promising. If it succeeds, researchers hope to use iPS cells to study other disorders and develop drugs to treat them. "That's the thing that would fundamentally change the way drug development happens," says Kyle Kolaja, director of early safety and investigative toxicology at Roche, which has partnered with Cellular Dynamics.

The last decade brought many difficult years for Thomson. His work on embryonic stem cells was a breakthrough, but it also brought intense controversy and media attention, turning him somewhat reclusive. With the rise of iPS cells and Cellular Dynamics, Thomson is beginning to come back to the limelight. "I think the legacy of embryonic stem cells will be that they gave rise to iPS cells," he says. "These cells will be used in creative ways we can't even imagine." —*Emily Singer*

THE CELL FACTORY James Thomson (1) and Junying Yu (2) first transformed adult cells into stem cells called iPS cells in 2007. Yu, now at Cellular Dynamics, is developing more efficient ways of making the cells (3), which are the starting ingredient used to make cardiac muscle cells. A precise combination of chemicals, agitation, and temperature transforms the iPS cells into heart cells (4), which fall to the bottom of the flask when it stops moving (5). Colonies of heart cells beat in sync when grown on a dish (6). Five weeks after iPS cells have been thawed, vials of muscle cells are ready to be shipped to customers (7).

10

Nanoparticles boost solar power's prospects

Light-Trapping Photovoltaics



SOLAR SPHERES By depositing nanoparticles made of silver on thin-film photovoltaic cells, Kylie Catchpole increases the cells' efficiency, which could make solar power more competitive.

MEGHAN PETERSEN

In 1995, finishing her undergraduate degree in physics, Kylie Catchpole decided to take a risk on a field that was nearly moribund: photovoltaics. "There was a sense that I might have difficulty ever being employed," she recalls. But her gamble paid off. In 2006 Catchpole, then a postdoc, discovered something that opened the door to making thin-film solar cells significantly more efficient at converting light into electricity. It's an advance that could help make solar power more competitive with fossil fuels.

Thin-film solar cells, which are made from semiconductor materials like amorphous silicon or cadmium telluride, are cheaper to produce than conventional solar cells, which are made from relatively thick and expensive crystalline wafers of silicon. But they are also less efficient, because if a cell is thinner than the wavelength of incoming light is long, that light is less likely to be absorbed and converted. At just a few micrometers thick, thin-film cells only weakly absorb wavelengths in the near-infrared part of the spectrum; that energy is lost. The result is that thin-film photovoltaics convert 8 to 12 percent of incoming light to electricity, versus 14 to 19 percent for crystalline silicon. Thus, larger installations are required in order to produce the same amount of electricity, limiting the number of places the technology can be used.

Catchpole, who is now a research fellow at the Australian National University in Canberra, began work on this problem in 2002 at the University of New South Wales in Sydney. "It was a case of 'start at the beginning: can you think of a completely different way to make a solar cell?'" she says. "One of the things I came across was plasmonics—looking at the strange optical properties of metals."

Plasmons are a type of wave that moves through the electrons at the surface of a metal when they are excited by incident light. Others had tried harnessing plasmonic effects to make conventional silicon photovoltaics more efficient, but no one had tried it with thin-film solar cells. Catchpole found that nanoparticles of silver she deposited on the surface of a thin-film silicon solar cell did not reflect back light that fell directly onto them, as would happen with a mirror. Instead, plasmons that formed at the particles' surface deflected the photons so that they bounced back and forth within the cell, allowing longer wavelengths to be absorbed.

Catchpole's experimental devices produce 30 percent more electrical current

KYLIE CATCHPOLE
(Australian National University) Making cheap solar cells more efficient

OTHERS WORKING ON LIGHT-TRAPPING PHOTOVOLTAICS
Harry Atwater, Caltech
Martin Green, University of New South Wales, Australia
Albert Polman, FOM-Institute for Atomic and Molecular Physics, Amsterdam

than conventional thin-film silicon cells. If Catchpole can integrate her nanoparticle technology with the processes used to mass-produce thin films commercially, it could shift the balance of technology used in solar cells. Thin-film photovoltaics could not only gain market share (they currently have just 30 percent of the market in the United States) but sustain growth in the solar industry overall.

Thus far, silicon has been losing out to cadmium telluride as the material of choice for thin-film solar cells. (First Solar, the market leader, is planning gigawatt-scale solar farms that will use cadmium telluride thin-film technology to deliver as much electricity as conventional power stations.) But tellurium is a rare material, and experts question whether the supply will support such grand ambitions. "There just isn't enough tellurium to make a substantial difference to the way the world's energy is produced," says Catchpole. "Silicon is the way to go."

Catchpole has been approached by companies, but she wants to refine the technology further before commercializing it. Meanwhile, researchers at Swinburne University of Technology in Melbourne are collaborating with Suntech Power, one of the world's largest manufacturers of silicon solar cells, on plasmonic thin-film silicon cells of their own. The company's plasmonic photovoltaics are expected to be ready for production within four years. *—Bob Johnstone*



Relying on relationships to rebuild TV audiences
Social TV

The viewership for live television broadcasts has generally been declining for years. But something surprising is happening: events such as the winter Olympics and the Grammys are drawing more viewers and more buzz. The rebound is happening at least in part because of new viewing habits: while people watch, they are using smart phones or laptops to swap texts, tweets, and status updates about celebrities, characters, and even commercials.

MARIE-JOSÉ MONTPETIT
(MIT) Social TV could improve the viewing experience and provide new business opportunities for carriers

OTHERS WORKING ON SOCIAL TV
BT, London, England
ClipSync, San Francisco, CA
Intel, Santa Clara, CA
Motorola, Schaumburg, IL

Marie-José Montpetit, an invited scientist at MIT's Research Lab for Electronics, has been working for several years on social TV—a way to seamlessly combine the social networks that are boosting TV ratings with the more passive experience of traditional TV viewing. Her goal is to make watching television something that viewers in different places can share and discuss—and to make it easier to find something to watch.

Carriers, networks, and content producers hope that making it easier for viewers to link up with friends will help them hold on to their audiences rather than losing them to services like Hulu, which stream shows over the Internet. And opening TV to social networking could make it easier for companies to provide personalized programming.

Many developers are working on ways to let people share the viewing experience over broadband connections or through set-top boxes; indeed, cable companies and other broadband video providers have sponsored small trials of various interactive TV services around the world for more than 20 years. But most of the systems were even clumsier than the combination of laptop and large-screen TV that

today's viewers have kludged together. Montpetit wants to unite different communication systems—especially cellular and broadband services—to create an elegant user experience. She's been sharing ideas about that sort of system with BT, which provides broadband connections to 15 million people in the United Kingdom and Ireland, including nearly a half-million digital-TV subscribers.

Though BT won't comment on what form its social-TV system might take, Montpetit and her students at the MIT Media Lab demonstrated an intriguing prototype last year. A central database aggregates video from online sources like YouTube, shares user-specified data with social networks, delivers video to the user's TV, and lets users and the people in their networks send comments and ratings back and forth via an iPhone app. It avoids using the TV screen for messages, something that has proved irritating to consumers who don't want clunky text obscuring the pictures on their 52-inch HDTVs. The app also allows the user to tell the network what program to show on his or her set. For instance, if a friend suggests a show and the owner agrees, that show will pop up at the appointed time. In February, Montpetit and her students presented a refined version of this system to BT. Jeff Patmore, who works with Montpetit as head of strategic university research at BT, says such a system could be rolled out this year, although he declines to confirm any plans. But Montpetit anxiously awaits U.S. deployment of social TV: her daughter, with whom she watches certain shows, heads off to college next fall. Engineering and business issues aside, she wants social TV to help friends and family stay connected, even as they move apart. *—William M. Bulkeley*

Storing carbon dioxide in cement
Green Concrete

Making cement for concrete involves heating pulverized limestone, clay, and sand to 1,450 °C with a fuel such as coal or natural gas. The process generates a lot of carbon dioxide: making one metric ton of commonly used Portland cement releases 650 to 920 kilograms of it. The 2.8 billion metric tons of cement produced worldwide in 2009 contributed about 5 percent of all carbon dioxide emissions. Nikolaos Vlasopoulos, chief scientist at London-based startup Novacem, is trying to eliminate those emissions with a cement that absorbs more carbon dioxide than is released during its manufacture. It locks away as much as 100 kilograms of the greenhouse gas per ton.

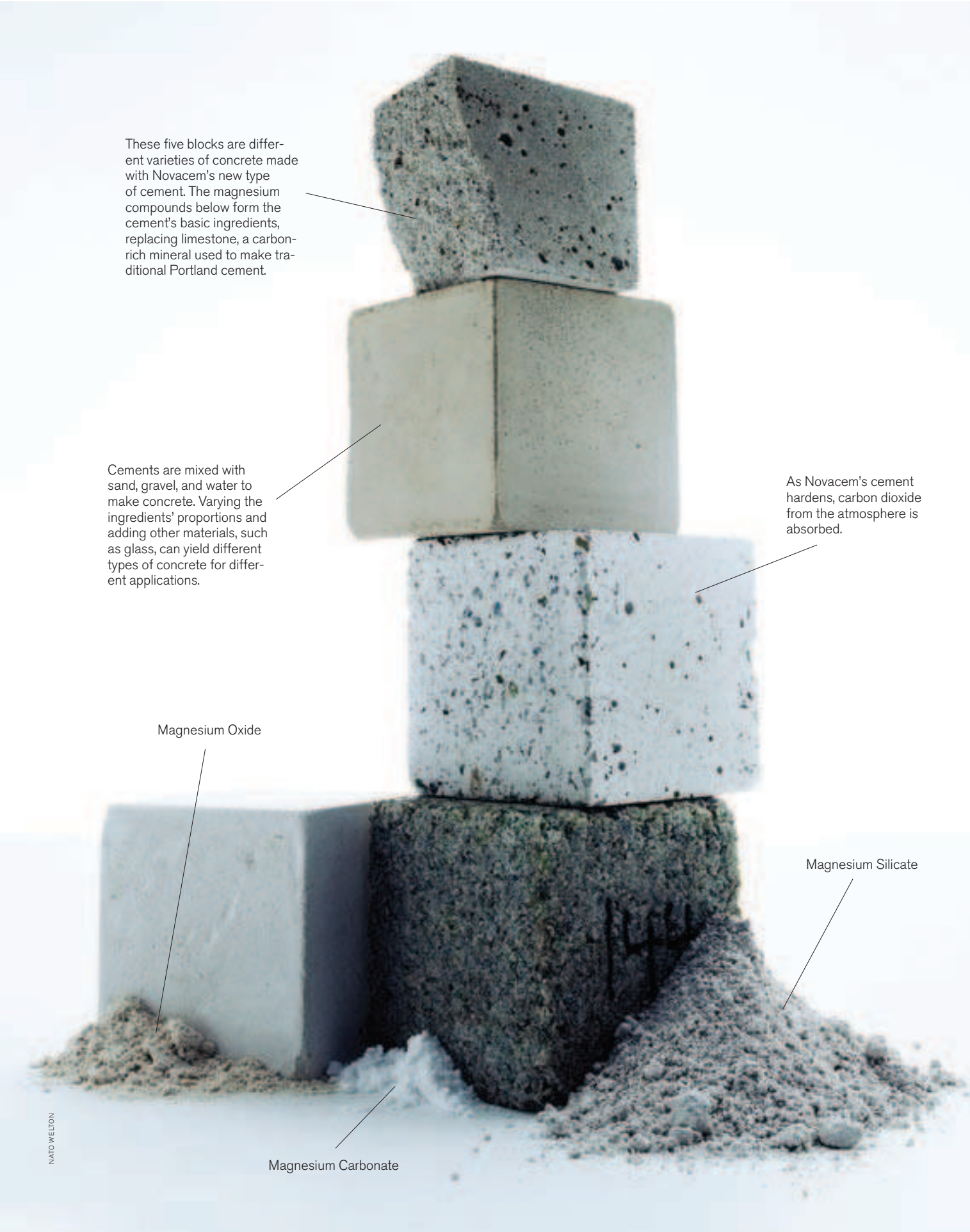
NIKOLAOS VLASOPOULOS
(Novacem) Green concrete could reduce global carbon emissions that are due to cement production

OTHERS WORKING ON GREEN CONCRETE
Kurt Zenz House, MIT
Calera, Los Gatos, CA
Joseph Davidovits, Geopolymer Institute, Saint-Quentin, France

Vlasopoulos discovered the recipe for Novacem's cement as a grad student at Imperial College London. "I was investigating cements produced by mixing magnesium oxides with Portland cement," he says. But when he added water to the magnesium compounds without any Portland in the mix, he found he could still make a solid-setting cement that didn't rely on carbon-rich limestone. And as it hardened, atmospheric carbon dioxide reacted with the magnesium to make carbonates that strengthened the cement while trapping the gas. Novacem is now refining the formula so that the product's mechanical performance will equal that of Portland cement. That work, says Vlasopoulos, should be done "within a year."

Other startups are also trying to reduce cement's carbon footprint, including Calera in Los Gatos, CA, which has received about $50 million in venture investment. However, Calera's cements are currently intended to be additives to Portland cement rather than a replacement like Novacem's, says Franz-Josef Ulm, director of the Concrete Sustainability Hub at MIT. Novacem could thus have the edge in reducing emissions, but all the startups face the challenge of scaling their technology up to industrial levels. Still, Ulm says, this doesn't mean a company must displace billions of tons of Portland cement to be successful; it can begin by exploiting niche areas in specialized construction. If Novacem can produce 500,000 tons a year, Vlasopoulos believes, it can match the price of Portland cement.

Even getting that far will be tough. "They are introducing a very new material to a very conservative industry," says Hamlin Jennings, a professor in the Department of Civil and Environmental Engineering at Northwestern University. "There will be questions." Novacem will start trying to persuade the industry by working with Laing O'Rourke, the largest privately owned construction company in the U.K. In 2011, with $1.5 million in cash from the Royal Society and others, Novacem is scheduled to begin building a new pilot plant to make its newly formulated cement. *—David Bradley*

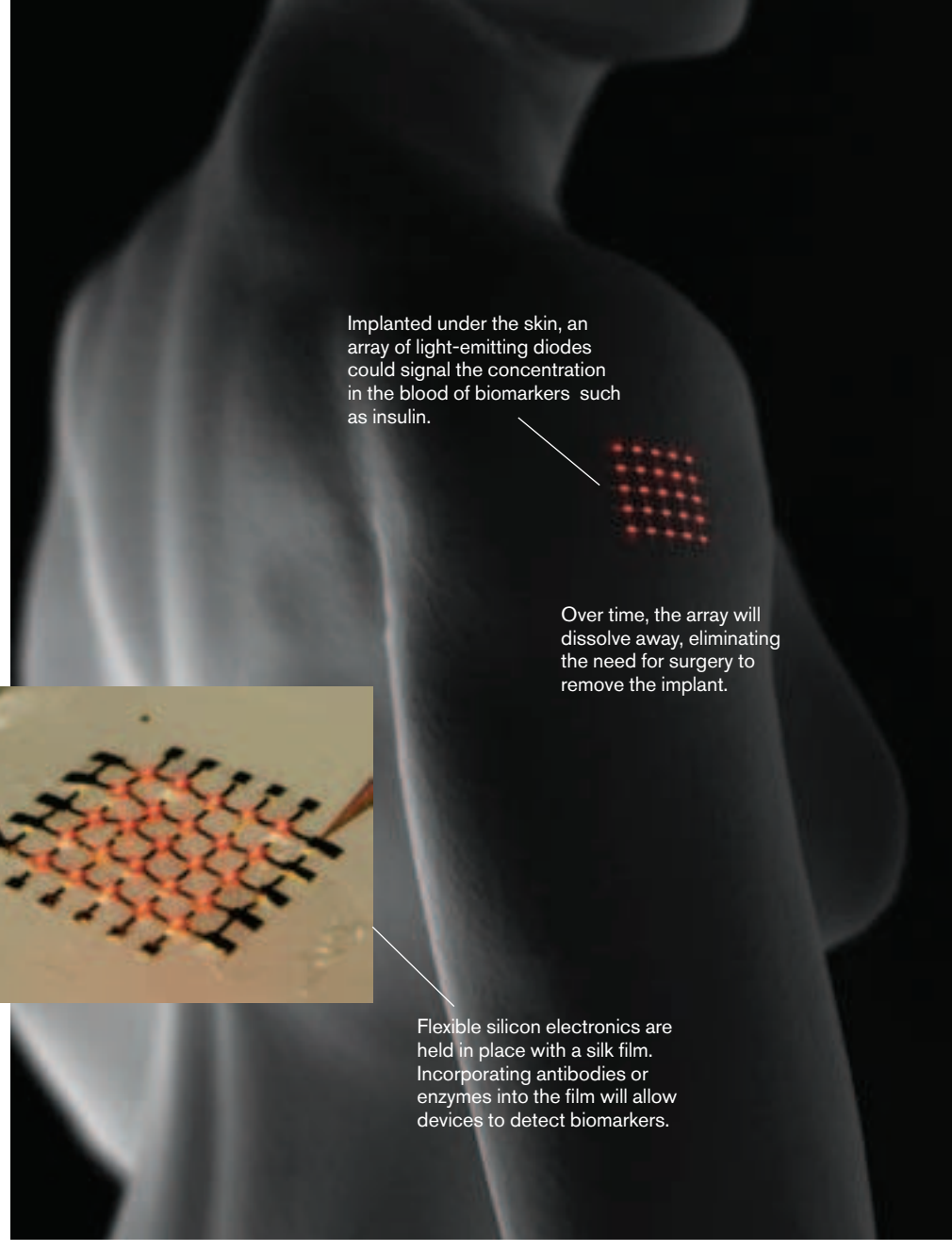

These five blocks are different varieties of concrete made with Novacem's new type of cement. The magnesium compounds below form the cement's basic ingredients, replacing limestone, a carbon-rich mineral used to make traditional Portland cement.
Cements are mixed with sand, gravel, and water to make concrete. Varying the ingredients' proportions and adding other materials, such as glass, can yield different types of concrete for different applications.
As Novacem's cement hardens, carbon dioxide from the atmosphere is absorbed.
Magnesium Oxide
Magnesium Silicate
Magnesium Carbonate

NATO WELTON

10

Dissolvable devices make better medical implants

Implantable Electronics



BRYAN CHRISTIE DESIGN

The next generation of implantable medical devices will rely on a high-tech material forged not in the foundry but in the belly of a worm. Tufts University biomedical engineer Fiorenzo Omenetto is using silk as the basis for implantable optical and electronic devices that will act like a combination vital-sign monitor, blood test, imaging center, and pharmacy—and will safely break down when no longer needed.

Implanted electronics could provide a clearer picture of what's going on inside the body to help monitor chronic diseases or progress after surgery, but biocompatibility issues restrict their use. Many materials commonly used in electronics cause immune reactions when implanted. And in most cases today's implantable devices must be surgically replaced or removed at some point, so it's only worth using an implant for critical devices such as pacemakers. Silk, however, is biodegradable and soft; it carries light like optical glass; and while it can't be made into a transistor or an electrical wire, it can serve as a mechanical support for arrays of electrically active devices, allowing them to sit right on top of biological tissues without causing irritation. Depending on how it's processed, silk can be made to break down inside the body almost instantly or to persist for years. And it can be used to store delicate molecules like enzymes for a long time.

Omenetto began working with silk three years ago, when David Kaplan, a biomedical engineer across the hall, asked for help making the material into complex scaffolds for growing new tissues. He boils silkworm cocoons and purifies the resulting solution to create his master ingredient, a water-based solution of the silk protein called fibroin. This solution can be poured into molds to make structures whose features are as small as 10 nanometers across. Omenetto has molded it into a wide variety of optical devices, such as lenses, mirrors, prisms, and optical fibers, all of which could be used to direct light to and from biosensors implanted in the body. Mixing antibodies or enzymes into the silk solution before molding it results in devices that could someday be used to sense low concentrations of just about any biological molecule, from glucose to tumor markers.

Collaborating with Kaplan and materials scientist John Rogers at the University of Illinois at Urbana-Champaign, Omenetto has produced implants that combine silk with flexible silicon electronics. For instance, the group has used

FIORENZO OMENETTO
(Tufts) Biodegradable electronics could make implantable devices easier on the body

OTHERS WORKING ON IMPLANTABLE ELECTRONICS
John Rogers, University of Illinois Urbana-Champaign, IL
Zhenan Bao, Stanford University Stanford, CA

silk films to hold in place arrays of tiny silicon transistors and LEDs—a possible basis for implantable devices that will help identify the concentration of disease markers. The researchers have shown that the devices function fine in small animals, with no evidence of scarring or immune response. The silk dissolves, leaving behind a small amount of silicon and other materials used in the circuits.

Another device uses silk as a substrate for a metal electrode mesh designed to replace spike-like electrodes used on the surface of the brain to diagnose and treat conditions such as epilepsy. When doused with saline solution, the silk wraps the mesh around the surface of the brain (even tucking it into the creases), helping the electrodes measure neural activity more precisely. The silk-based electrodes will probably be the first of the group's devices to be tested in people, perhaps in two to three years.

Omenetto sees other possibilities further in the future: for example, a silk optical fiber could transmit light from an LED array to an implanted silk sensor, which would change color to indicate that a cancer has come back. The device might then release a precisely calibrated dose of a drug. A second silk fiber could transmit that information to the surface of the patient's skin, where the output might be read by a cell phone. All the components for making such things exist, Omenetto says. Once the pieces are brought together, a little silk will help save lives. *—Katherine Bourzac*

TOBY BURDITT



Joseph Hellerstein wants cloud programmers to reach new heights.

A new language will improve online applications

Cloud Programming

Cloud computing offers the promise of virtually unlimited processing and storage power, courtesy of vast data centers run by companies like Amazon and Google. But programmers don't know how best to exploit this power.

Today, many developers are converting existing programs to run on clouds, rather than creating new types of applications that could work nowhere else. And they are held back by difficulties in keeping track of data and getting reliable information about what's going on across a cloud. If programmers could solve those problems, they could start to really take advantage of what's possible with a cloud. For example, an online music retailer could monitor popular social-media feeds; if a singer suddenly became a hot topic, advertising and special offers across the retailer's site could be instantly reconfigured to make the most of the spike in interest.

At the University of California, Berkeley, Joseph Hellerstein thinks he can make it much easier to write complex cloud applications by developing software that takes over the job of tracking data and keeping tabs on what's happening. His big idea is to modify database programming languages so that they can be used to quickly build any sort of application in the cloud—social networks, communication tools, games, and more. Such languages have been refined over

10

JOSEPH HELLERSTEIN
(University of California, Berkeley)
Better software for building cloud applications

OTHERS WORKING ON CLOUD PROGRAMMING
Yahoo Research, Silicon Valley, CA
Microsoft eXtreme Computing Group, Redmond, WA
IBM Research, Yorktown Heights, NY
Cornell Database Group, Ithaca, NY

the years to hide the complexities of shuffling information in and out of large databases. If one could be made cloud-friendly, programmers could just think about the results they want, rather than micromanaging data.

The challenge is that these languages process data in static batches. They can't process data that is constantly changing, such as readings from a network of sensors. The solution, Hellerstein explains, is to build into the language the notion that data can be dynamic, changing as it's being processed. This sense of time enables a program to make provisions for data that might be arriving later—or never.

The result is called Bloom. So far, Hellerstein's group has used the Bloom language and its predecessors to quickly rebuild and add major features to popular cloud tools such as Hadoop, a platform used to manipulate very large amounts of data. By lowering the complexity barrier, these languages should increase the number of developers willing to tackle cloud programming, resulting in a wave of ideas for new types of powerful applications.

Hellerstein's group is getting Bloom ready for a release in late 2010. They and others are also working on demonstrating how the techniques can be used for real-time applications such as online multiplayer games, or to watch for the warning signs of an earthquake or tsunami. *—Erica Naone*

Fighting cancer more efficiently
Dual-Action Antibodies

At Genentech's sprawling headquarters south of San Francisco, senior scientist Germaine Fuh has been genetically redesigning two of the company's most lucrative cancer drugs. One, Herceptin, is a monoclonal antibody that shuts down HER2, a growth accelerator in about 20 percent of breast tumors. The other, Avastin, is an antibody that blocks a protein that stimulates the formation of tumor-feeding blood vessels. Last year the drugs had combined sales of $11 billion; a full course of Herceptin at wholesale costs about $43,000, while treating a breast cancer patient with a full course of Avastin costs about $55,000. Fuh's goal: to show she can provide greater benefit for people fighting breast cancer by combining the action of the antibodies in one molecule. Last year, she and her coworkers showed that a modified version of the Herceptin antibody not only shut down the HER2 receptor in mice but also locked onto VEGF, Avastin's target.

GERMAINE FUH
(Genentech) Dual-action antibodies, which latch onto more than one target, may provide the benefits of combination therapy at lower cost

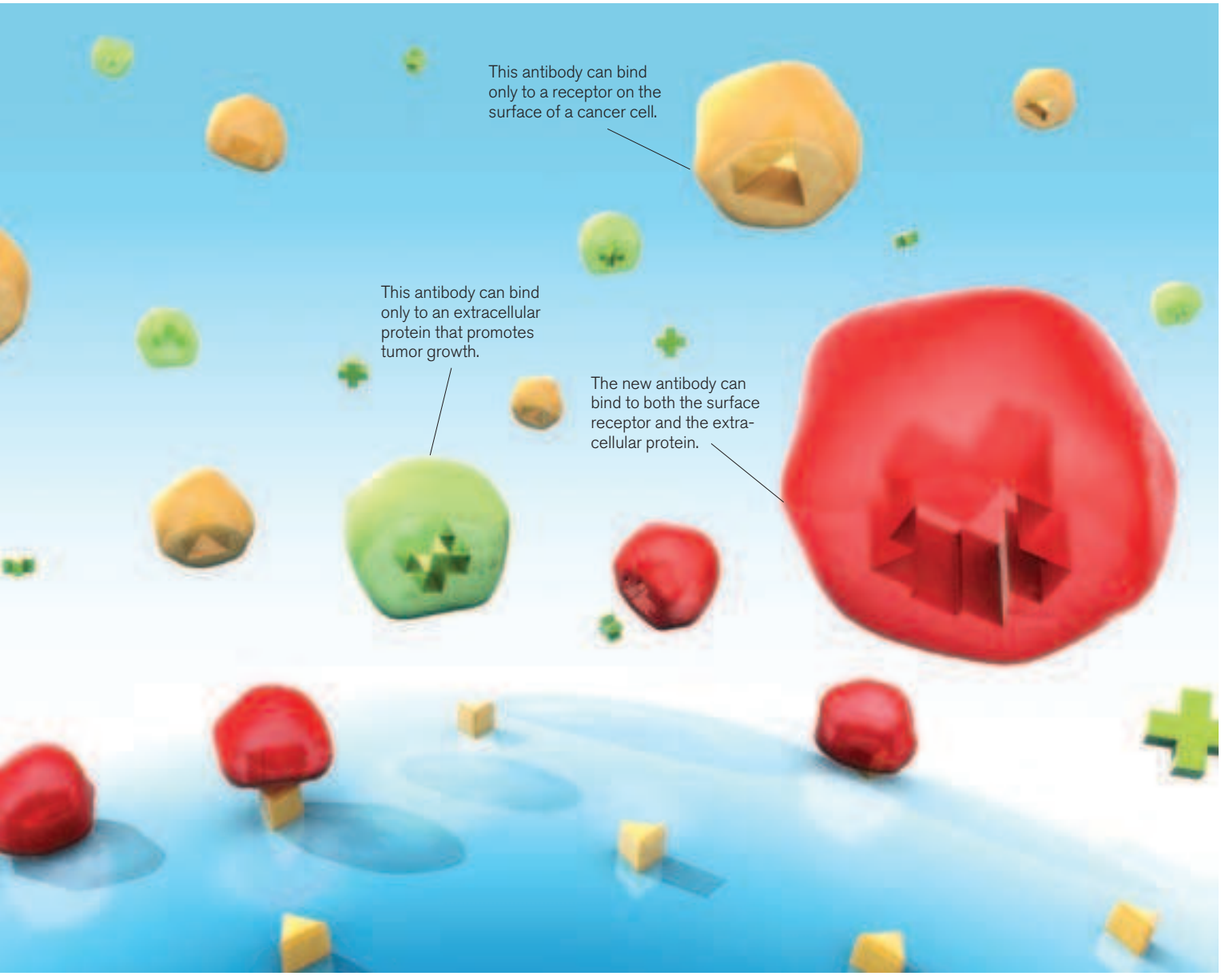
OTHERS WORKING ON DUAL-SPECIFIC ANTIBODIES
Biogen Idec, Cambridge, MA
CovX, a unit of Pfizer, La Jolla, CA
Domantis, a unit of Glaxo-SmithKline, Cambridge, England
Trubion Pharmaceuticals, Seattle, WA

Designing such "dual-specific" antibodies could help solve a major problem with chemotherapy drugs: cancer cells can become resistant to them, mutating in ways that allow them to dodge the medication's action. Doctors often mix various chemotherapy drugs in an effort to kill cancers before they can exploit this escape mechanism. Having a single drug that can hit the cancer from multiple directions would simplify treatment.

A single monoclonal antibody that could do the work of two is also attractive from a business perspective. It might cost half as much to manufacture as two separate antibodies, and the path to regulatory approval might also be shorter and less expensive, involving one set of clinical trials instead of multiple trials for two separate drugs in various dosage combinations. Genentech has started trials to determine whether Herceptin and Avastin together will fight breast cancer better than either used alone, but the cost of such studies is a big disincentive to doing them regularly.

Fuh's research into whether one antibody drug could be redesigned to do the work of two began six years ago. An antibody, one of the immune system's most robust weapons, is a Y-shaped protein about 10 nanometers long. At the tip of each branch is an active site, which grabs a specific molecule on an invading microbe or cancer cell. Swarms of antibodies disable the invader, marking it for destruction by white blood cells or other immune molecules.

Fuh notes that many mammalian antibodies have some ability to bind to a second antigen, but typically they do so weakly. Her goal was to exploit this ability while making both bonds tight and functional. Fuh's team induced subtle mutations at the tips of Herceptin and screened 10 billion mutant clones



BRYAN CHRISTIE DESIGN

TWO FOR THE PRICE OF ONE Antibody drugs work by binding to antigens such as extracellular proteins or receptors on a cell's surface, blocking their ability to function or targeting them for destruction by the immune system. Genentech's new antibodies can bind to two different antigens, potentially reducing the number of drugs required to treat diseases.

for activity against VEGF. They netted several candidates—including one with active sites that could bind to both HER2 and VEGF strongly enough to limit tumor growth.

Genentech, now a wholly owned subsidiary of Swiss pharmaceutical giant Roche, is using this technique to develop another dual-specific drug, which may soon be ready for clinical trials. Fuh won't disclose the details of what the drug is for and will only say, "Right now, we are very close."

Meanwhile, her experiments have fueled interest in the overall potential of such drugs. "The two-for-one drug concept is important, especially for indications like cancer," says Carlos Barbas III, a professor of molecular biology at the Scripps Research Institute in La Jolla, CA. Barbas is the founder of CovX, a company working on a different approach to making dual-specific antibodies (Pfizer acquired it in 2008). Despite the competition, he praises the accomplishment of the Genentech team as "a beautiful piece of antibody engineering."

The implications of Fuh's research are indeed far-reaching. If the concept proves successful, antibodies that stick to two targets might be used to treat infectious diseases as well as cancer—offering the promise of drugs that work better and cost less. *—Sabin Russell*

China's Internet Paradox

Will China's Web, like its larger economy, comfortably combine extraordinary growth with government repression?

By DAVID TALBOT

On March 23, the day after Google pulled its search operations out of mainland China, a woman who uses the online pseudonym Xiaomi arose in her Shanghai apartment and sat down in her bedroom office for another day of outwitting Internet censorship. She leads a confederation of volunteer translators around the world who turn out Mandarin versions of Western journalism and scholarly works that are banned on China's Internet—and that wouldn't be available in Mandarin in any case. That day, working in a communal Google Docs account, she and her fellow volunteers completed translations of texts that ranged from a fresh *New York Times* interview with Google cofounder Sergey Brin to "The Limits of Authoritarian Resilience," a seven-year-old analysis of China's Communist Party from the *Journal of Democracy*.

What happened when Xiaomi hit "Post" reveals that the government's constraints have their limits. The pieces went live on a blog (http://yyyyiiii.blogspot.com) and a public Google Docs page (http://zxc9.com/2z0001). These links were broadcast to the nearly 4,000 people who follow her on Twitter (as @xiaomi2020), the 1,170 more who follow her on Google Buzz, and others on five Chinese Twitter clones. Although Blogspot and Twitter are blocked in China to those without circumvention software, anybody in the country can open the Google Docs page—at least for now. (The government did block Google Docs for a time last year but relented after protests from companies and universities.) Once posted, Xiaomi's translations are often reposted 10,000 times or more on blogs and bulletin-board-style discussion sites. There, they can survive for various lengths of time, though the hosting services—which are required to self-censor—generally take them down. The total readership may be orders of magnitude higher than the number of postings, since each post is presumably read by many people, some of whom also copy the translations into group e-mails.

Xiaomi takes steps to preserve her anonymity and avoid runins with the authorities. (Such encounters often start when police summon someone to the local station to "drink tea"—the euphemism for questioning designed to let people know they are being watched—and can end with imprisonment.) She uses Gmail (which is encrypted and hosted outside China) and technologies that make her computer's Internet Protocol address appear to come from the United States (the address changes frequently to thwart blocking). When she needs to talk, she uses the encrypted Internet voice service Skype—a version she installed in the United States, not one available in China that was found to allow surveillance.

What she achieves with the help of such tools is hardly the only example of free speech and protest percolating through China's censored Internet. In recent years Internet-based campaigns—efforts that often blossom on bulletin boards and blogs in hours or days—have pressured the Chinese government to release prisoners, launch investigations into scandals such as the kidnapping of boys conscripted into slave labor, and imprison corrupt government officials. "The Internet has empowered the Chinese people more than the combined effects of 30 years of [economic] growth, urbanization, exports, and investments by foreign firms," says Yasheng Huang, a China expert and professor of international management at MIT's Sloan School. "China may not have free speech, but it has freer speech, because the Internet has provided a platform for Chinese citizens to communicate with each other." And that communication can include criticism of the government.

China's attempts to suppress Internet speech have intensified. But they have intensified partly because there's so much more mate-

Photographs by JUSTIN GUARIGLIA



CHINA CHAT
A woman peruses the online discussion site QQ.com—one of China's most popular websites—in a Shanghai Internet café.

rial online—maybe overwhelmingly more—for the government to worry about. China's Internet, like its economy in general, is exploding in size and complexity. The country now has a staggering 384 million Internet users—nearly a quarter of the world total—plus 750 million mobile-phone users, many of whom use those phones to access the Web. That rapid growth of the network, coupled with the remarkable creativity and boldness of its users, is shaping the Chinese Web at least as powerfully as is government repression. "We underestimate the vitality of the Chinese Internet," says Ethan Zuckerman, cofounder of Global Voices, a blogging advocacy group. "We hear it is censored and therefore assume every page has a red background and text from the central propaganda agency. We badly underestimate how vital and how interesting some of those conversations can end up being. This is now the largest Internet, bigger than that of the United States. Why do we have a blind spot around this? We assume censored means 'Dead. Lifeless. Artificial.' What 'censored' actually means is 'really, really complicated.'"



"We underestimate the vitality of the Chinese Internet. ... We assume censored means 'Dead. Lifeless. Artificial.' What 'censored' actually means is 'really, really complicated.'"

A HIGHER FIREWALL

The Chinese government operates the world's most sophisticated national Internet filtering system. Though often called the Great Firewall, it is not one entity but, rather, a mix of strategies. Filters at the ISP level block banned Western websites (including YouTube, Facebook, Twitter, Blogger, and the *Guardian*'s site) and can block websites whose URLs contain any of an ever-growing list of banned keywords related to politically sensitive topics. The government stepped up its efforts in 2009, especially before the 20th anniversary of the Tiananmen Square crackdown on June 4 and the 60th anniversary of China's National Day on October 1. The regime even unplugged the entire Net in the Urumqi region to block reports of violent protests over the ethnically motivated murders of migrant workers. Finally, the government for a short time required that all computers be sold with porn filtering software known as Green Dam preinstalled. (Faced with international and domestic outrage when it emerged that the filter also blocked political speech—and was buggy and insecure regardless of its intended function—officials announced an indefinite delay.) It was a hacking attack that Google said had targeted the Gmail accounts of human rights activists that precipitated the company's March decision to stop censoring search results and shut down its site in mainland China.

To get around the blocks, some people use tools such as Ultrareach, Dynaweb, and Tor *(see "Dissent Made Safer," May/June 2009 and at technologyreview.com)*, which enable them to connect to banned websites via proxy computers outside the country. But government censors have increasingly been blocking the proxies, too. And in truth, most Chinese Internet users don't bother with Western sites at all. Over the past decade, homegrown alternatives to popular Western Web 2.0 sites have become extraordinarily popular. Instead of Facebook, China has Douban, whose users are generally anonymous and gravitate toward topics such as movie and book critiques rather than personal news. Instead of YouTube, China has YouKu, which naturally tilts toward Chinese topics. China's bulletin-board sites—led by QQ, the second most popular website in China and the 10th most popular in the world—are teeming with debates over current events. Hal Roberts, a fellow at the Berkman Center for Internet and Society at Harvard and a leading researcher on Internet filtering and surveillance, says that sites hosted in China account for about 95 percent of page views there. "Whereas a country like Turkey will get upset at a video about the Armenian genocide and block YouTube," he says, "China blocks YouTube but also gives people YouKu, which is censored, but which they say is better anyway, natively in Mandarin, and run by Chinese people."

The Chinese government allows these sites to flourish only because they have agreed to censor themselves. But the forbidden topics are not clearly defined, and the extent of the censorship varies. "In China everyone knows there are hidden rules," says Isaac Mao, a Chinese software engineer and venture capitalist based in Shanghai, who became one of China's first bloggers in 2002. Criticism of the regime, promotion of democracy, and advocacy of human rights or Tibetan independence are often censored; so is discussion of specific incidents and scandals ranging from the Tiananmen Square crackdown of 1989 to the Sichuan earth-







NETWORK EFFECTS China's Internet has 384 million users—more than that of any other country. Ninety-five percent of its traffic goes to Chinese sites, which are subject to growing censorship. But citizens have built vibrant Web 2.0 networks and used them to root out corruption, win the release of imprisoned bloggers, and trigger investigations into the enslavement of boys in brick-making factories.

quake scandal of 2008, in which the collapse of many shoddily built school buildings contributed to the deaths of more than 5,000 children. The Chinese government increasingly imposes heavy fines or shutdowns—or even jail time for principals—to make local Web companies follow these implicit rules. A few years ago, a government officer would "call your phone, ask you to delete some article in one day, or in [a few] hours," says Huo Ju, a computer programmer in Shanghai, who runs a technology blog that is blocked in China. "The Chinese government didn't close websites or companies. But in 2009, many websites [were] closed. They also delete articles, and they try to control opinion direction." Meanwhile, the government rewards good behavior. Rebecca MacKinnon, an expert on the Chinese Internet who is now a visiting fellow at Princeton University's Center for Information Technology Policy, wrote of attending a government event in Beijing last November at which executives from 20 Chinese Internet companies were awarded the 2009 China Internet Self-Discipline Award for censoring themselves in the interest of "harmonious and healthy Internet development." "China can use offline methods of control," says Roberts. "At the end of the day, it is more effective to send government agents to people's doors than to filter the Net."

China's users filter themselves, too. The Tianya.cn bulletin board, with more than 35 million members, manages a kind of wiki-style self-censorship. Posts are ruled on by communities of "board masters" (ordinary users elected by other members); if they cut a post, the poster can appeal to a higher-tier editor in a complaint forum. A board master can be dismissed if enough people complain. This in some sense mirrors the way Chinese society works, and Donnie Dong, a Chinese lawyer and Internet scholar who is now a fellow at the Berkman Center, says it is readily accepted. "The reality is that the condition in China has changed the structure of the Internet into something distinct," he says. He calls it the "Cinternet"; Xiaomi and some others call it the "Chinternet." Either way, says Dong, "the law, including statutes and the 'living law,' is making and changing the code."

PROTESTS GO VIRAL

But this living law has neither checked the overall expansion of Web access nor stanched the online activism that tests the limits of censorship—especially on internal Chinese sites. The Chinese search engine Baidu offers discussion forums that—although cleansed of political topics—are extremely popular. One day last summer, an anonymous member posted something on a Baidu forum devoted to the online game World of Warcraft, and it became an Internet meme: *Jia Junpeng, your mother wants you to go home to eat*. The cheeky, mysterious sentence received seven million hits and 300,000 comments on the first day. People built humorous dialogues around it; graphics made it appear as if the command had been uttered by Barack Obama, Saddam Hussein, or Chinese military officials posing for a formal Communist Party portrait.

Then the goofy phenomenon took a sharp political turn. Around the time the post originally appeared, a famous blogger named Guo Baofeng was arrested for posting allegations of an official cover-up in the brutal rape of a 25-year-old woman named Yan Xiaoling in Mawei, a district in the city of Fuzhou. She later died of her injuries. Before his incarceration, Guo managed to squeeze off a couple of short blog posts. "I have been arrested by Mawei police SOS," read one. Even in repressive China, there's no law against exhorting people to go home to their mothers. Bloggers began calling on people to send postcards to the Mawei police: *Guo Baofeng, your mother wants you to go home to eat*. Similar messages sprouted on bulletin-board sites. A few days later, Guo was released; he later attributed his freedom to the Internet-generated "postcard movement." The use of Web 2.0 in the Guo case "is fascinating, and it is also revealing about some of the general features of online social activism in China today," says Guobin Yang, a sociologist and China Internet scholar at Columbia University. "Compared with the student movement in 1989, where people had large-scale gatherings, today's activists work on special issues, like calling for the release of a particular person or dealing with corruption or environmental pollution through very creative means. Much of this is happening on the Internet, with a lot of impact."

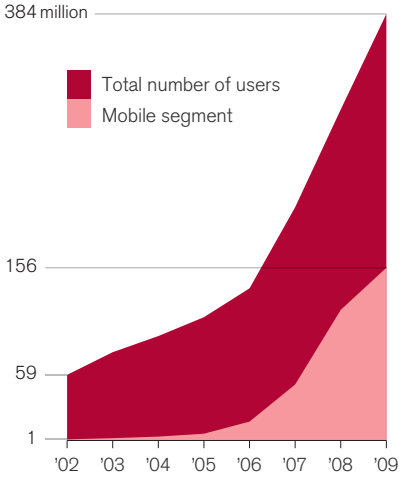
Sometimes the Chinese Web simply amplifies citizen outrage, forcing government action. In 2007 a local newspaper in Henan province reported a kidnapping scandal: boys were being snatched to work as slaves in brick kilns. The issue failed to excite the interest of national authorities until a woman posted a letter about it on a local online bulletin board. The letter was cross-posted to Tianya and went viral, garnering 580,000 hits there and many more on other forums, according to an analysis of the case by Yang. The attention prompted the central government to investigate and prosecute two people. And in Nanjing, amid anger over high housing prices, local bloggers broadcast the fact that Zhou Jiugeng, a former director of a government property-management bureau, was driving to work in a Cadillac and wearing an expensive watch. The revelation led to an investigation—and an 11-year prison sentence for Zhou, who was found to have been accepting bribes.

Even lawyers and judges are testing the limits. Anne Cheung, a law professor and Internet researcher at Hong Kong University, says she and her colleagues are finding previously unheard-of criticism of the regime. One lawyer, Xu Zhiyong, often blogs about the plight of citizens who try to lodge legal complaints in Beijing but end up in secret jails (see http://xuzhiyong.fyfz.cn). Some government officials are criticized by name. Criticism of the Chinese Communist Party used to be "a sensitive area," Cheung says, "but now, somehow, the authorities will tolerate that." In general, "if you have the courage to raise your voice, then you may be able to get something out of the Internet and Web 2.0," she adds.

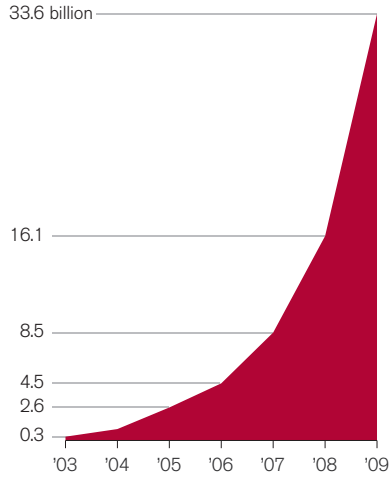
THE EXPLODING GROWTH OF CHINA'S WEB

The number of Web users in China is surging—by one estimate it will hit 900 million in 2014—and the number of Web pages is also rising sharply.

Internet users in mainland China

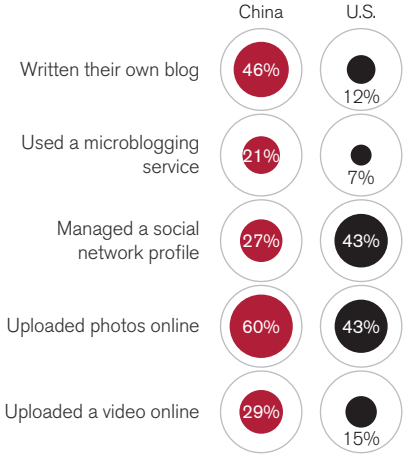


Number of Web pages in mainland China



Chinese Web users are more participatory than their U.S. counterparts.

Percentage of Web users who have….



Sources: China Internet Network Information Center; Trendstream, Lightspeed Research

TOMMY McCALL



BANNED IN CHINA Huo Ju, a programmer in Shanghai whose technology blog is blocked, says Chinese Internet repression is worsening; the government closed many websites in 2009. But such control efforts face higher hurdles as the Chinese Internet explodes in size and complexity.

INTERNET CONSENSUS?

A swiftly growing Chinese Internet; restrictions by the central government; a degree of collusion with those restrictions among Web companies and the public, so long as they are not onerous to business; a calculation by the government that permits some dissidence: all this might amount to an Internet version of the Beijing Consensus, a catchall term for alternative models of economic development that take China's success as an example. The Chinese government has a long tradition of managing dissent. And Cheung thinks the two trends—growing governmental control of the Web on the one hand and online growth, creativity, and activism on the other—will continue pushing and pulling on each other for some time. Progress toward Internet openness "may be incremental, not moving in a linear direction," she says. "I would say this is consistent with Chinese style—loosening sometimes, but tightening sometimes. You can't really predict."

To break the stalemate and tear down the Great Firewall, some activists and members of Congress have advocated that the West push on two fronts. One is purely technological: make available far more proxy computers, those neutral IP addresses in other countries from which users in China can access an entirely open Internet. But that would be costly—and in any case most Chinese use only Chinese sites, which are subject to self-censorship, not network-level blocking. The second tactic is to apply pressure through Western companies that are deeply involved in the Chinese Internet—companies that provide the routers, the filtering software (variations on the technology that filters pornography and other content in other countries), and the PCs that Chinese consumers buy. The Global Network Initiative (GNI), a consortium of corporations, academics, and human rights groups that formed in 2008, is working on a voluntary code of corporate conduct to support free speech and human rights, but to date only Microsoft, Google, and Yahoo have signed on (the latter company after it gave Chinese authorities data on activists named Li Zhi and Shi Tao, resulting in their imprisonment). "It's better to join the GNI before you get stuck with a Yahoo case ... rather than wait until they are yelling at you in Congress and calling you moral pygmies," says MacKinnon, a cofounder of the GNI. But as MacKinnon pointed out in a recent blog post, these ideas go only so far; the only Chinese anticensorship techniques that will work on a large scale will be ones generated by the Chinese themselves. Zuckerman adds that well-meaning Westerners would do well to at least become familiar with Chinese online norms and customs. "Until we understand what Chinese users like and want and use, it's hard for us to understand how we would design alternatives to censorship that are likely to succeed," he points out.

That's where activists such as Xiaomi fit in. "Some people will wonder who is doing this, and why," she said, speaking to me through her secure Skype connection. Her motivations, she explained, are the same as those that drew her, as an undergraduate in 1989, to the democracy protests in Tiananmen Square. She recalls a Woodstock-like experience, with people singing and falling in love as they camped out. She left on May 28, 1989—one week before the crushing response by Chinese tanks and soldiers—and went on to earn an MBA at a U.S. school and prosper as a software consultant. "In my generation, most of us have done well. We caught the opportunity of China's booming economy," she said. "But there are dreams that are not fulfilled yet. We had them for more than 20 years, and things are still getting even worse and not better."

Huang, of MIT, argues that the protestors of Tiananmen might never have imagined seeing the criticisms of policies and officials that are online today. "We should measure progress in China not by protests on the streets and availability of news on protests, but by the involvement of the Chinese citizens in policy discussions," Huang says. "By the latter yardstick, China has made huge progress, thanks largely to the Internet. The Internet is already changing China, and it will change the country for the better in the future." China's Internet, like its society and economy as a whole, might move fitfully and incrementally toward greater freedom. Because as activists like Xiaomi grow more creative—and the Great Firewall grows more sophisticated—the Chinese Internet is simply ... growing. And even Xiaomi, who experiences the Great Firewall firsthand and is less optimistic than Huang, believes that the wall "eventually will fail." TR

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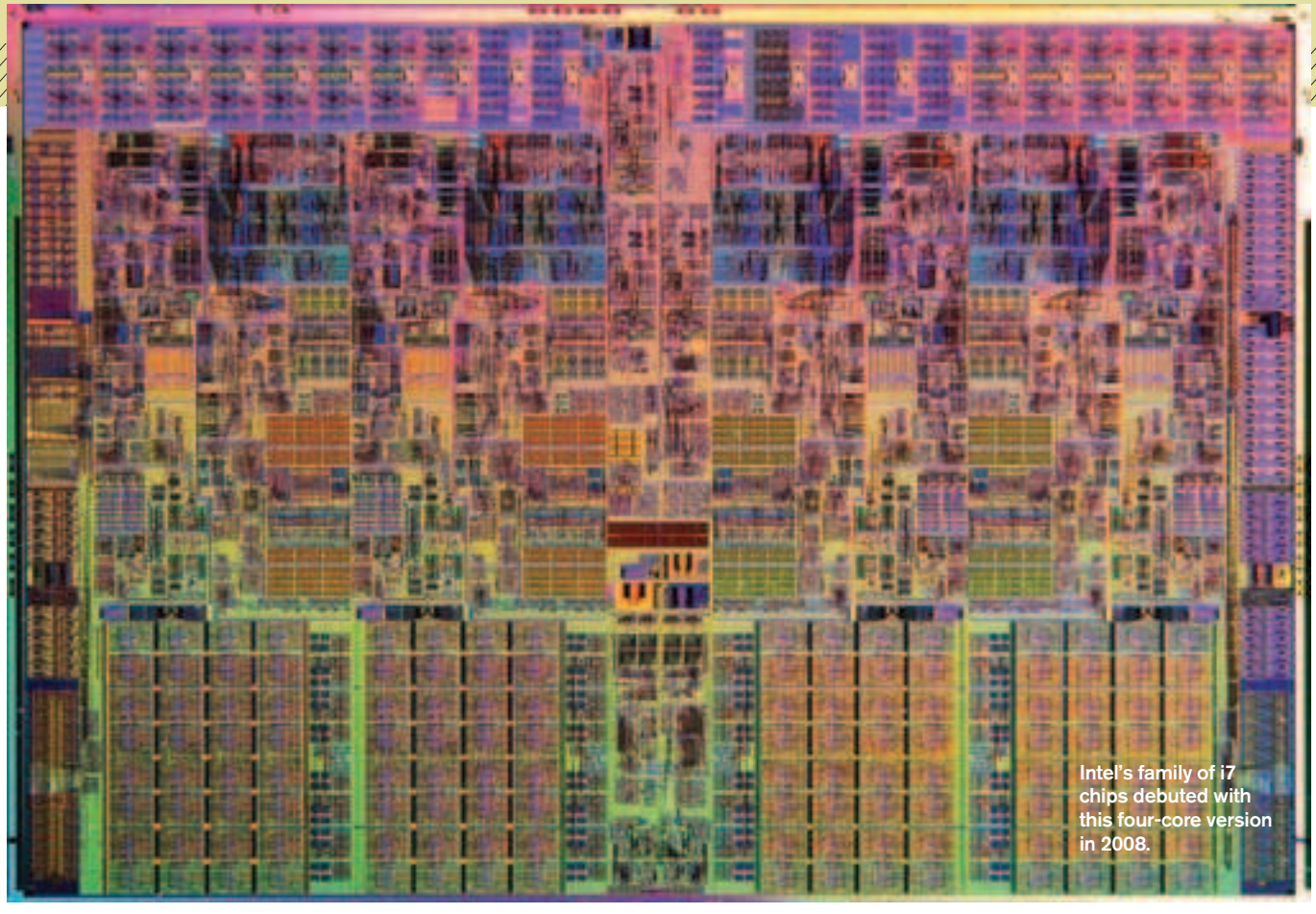
[1]Based on planned 1ku pricing for AMD Opteron™ processor Model 6128 at launch ($266 ÷ 8 cores = $33/core). [2]Internal testing at AMD performance labs as of 2/17/10 showed a 2.13x performance gain (estimate) for 2x AMD Opteron processor Model 6172 ("Magny-Cours") over 2x Six-Core AMD Opteron processor Model 2435 ("Istanbul") running SPECfp®-rate2006. Configuration: "Dinar" reference design, 64GB (16 x 4GB DDR3-1333) memory, 250GB SATA disk drive, SUSE Linux® Enterprise Server 10 SP2 64-bit; Supermicro A+ Server 1021M-UR+B server, 32GB (8 x 4GB DDR2-800) memory, 20GB SATA disk drive, Red Hat Enterprise Linux® Server 5.3 64-bit. [3]Based on comparison of Six-Core AMD Opteron processor Model 2435 (6 cores; $989 suggested 1ku price) vs. AMD Opteron processor Model 6172 (12 cores; $989 planned 1ku price at launch).

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BRIEFING

MICROPROCESSORS



Intel's family of i7 chips debuted with this four-core version in 2008.

INTEL

Mobile computing is transforming the microprocessor industry

Intel's family of Core i7 chips, which are among today's most powerful desktop processors, have as many as 774 million transistors, with channels just 100 silicon atoms across. The chips have four to six 64-bit computational cores that run at clock speeds of up to 3.3 gigahertz. In volume, one costs about $1,000; correcting for inflation, that's about what the first commercial microprocessor, the Intel 4004, cost in 1971. Incredible advances in silicon technology over the last 40 years have made computers ubiquitous in homes and offices.

Microprocessors have also become commonplace in mobile devices such as cell phones, but until recently there was a vast gulf between the simple processors embedded in such things and their more complex cousins in personal computers. In the last few years, however, mobile processors have vastly increased in capability. Today, a smart phone might have a one-gigahertz processor and gigabytes of data storage, roughly equivalent to the computational power that a high-end desktop computer had in 2000. The implications are immense. The multimedia capabilities of modern cell phones are enabling millions of people in poor countries to access the Internet. And new mobile appli-

cations, such as location-based services and augmented reality, are moving into the mainstream.

The surging demand for mobile computing power is changing the way the semiconductor industry thinks about chips *(see "Mobile Chips Threaten High-Performance Manufacturers," p. 76).* The constraints of batteries mean that performance per watt is replacing processing power as the metric that chip makers like to brag about. And the emphasis on networking and multimedia applications in mobile devices is moving manufacturers' focus from general-purpose processors to those that have specialized circuitry for tasks such as handling audio and video *(see "Designing for Mobility," below).* Manufacturers are also working out how to accommodate the limitations of silicon, which are making it harder and harder to deliver ever more processing power at an ever lower price *(see "The High Cost of Upholding Moore's Law," opposite).* Yet some of the biggest performance gains we'll see in the next few years won't come from new ways of making chips but from new ways of programming them *(see "Multicore Processors Create Software Headaches," p. 74). —Stephen Cass*

TECHNOLOGY OVERVIEW

Designing for Mobility

Anticipating the ever-increasing computing demands of tomorrow's mobile devices, chip makers are rolling out compact designs for processors that boost performance while drawing less battery power.

Designing processors for mobile devices requires more than simply reproducing desktop computer architecture in a smaller device. The tinier transistors get, the more electricity they leak, a killer for battery-powered devices. To address this problem, Intel has incorporated better insulating materials into its current generation of chips, and IBM's chips will soon have a honeycomb design with empty spaces—because a vacuum is the best insulator of all.

Another strategy is to package multiple processing units on the same chip, a technology called multicore computing. Instead of, say, a single power-hungry two-gigahertz chip, two energy-efficient, one-gigahertz cores could deliver the same performance. But programming multicore processors effectively can be tricky *(see "Multicore Processors Create Software Headaches," p. 74).*





Apple's iPad is powered by a chip the company designed specifically for the tablet computer: the one-gigahertz A4.

APPLE

Packaging specialized systems with a general-purpose core can also be a way to boost performance for specific mobile applications, such as handling multimedia. Apple used this approach for its iPad tablet computer, creating a custom chip called the A4 to power the device. Qualcomm, Intel, and IBM are each taking this idea a step further by working on designs for three-dimensional chips with multiple layers of circuitry. These designs save energy by shortening the distance bits must travel between, for example, the processor and a memory chip (the longer the path electrons must travel, the more are lost to heat). Qual-

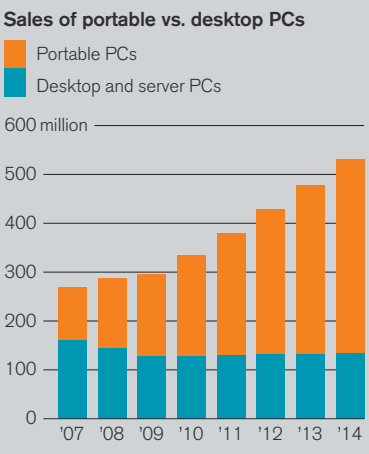
DATA SHOT

22.3%

The growth rate in the number of Internet-connected mobile devices that's expected every year through 2013, according to market research firm In-Stat.

MOVING MACHINES

Desktops face a dwindling global market share.



Source: IDC

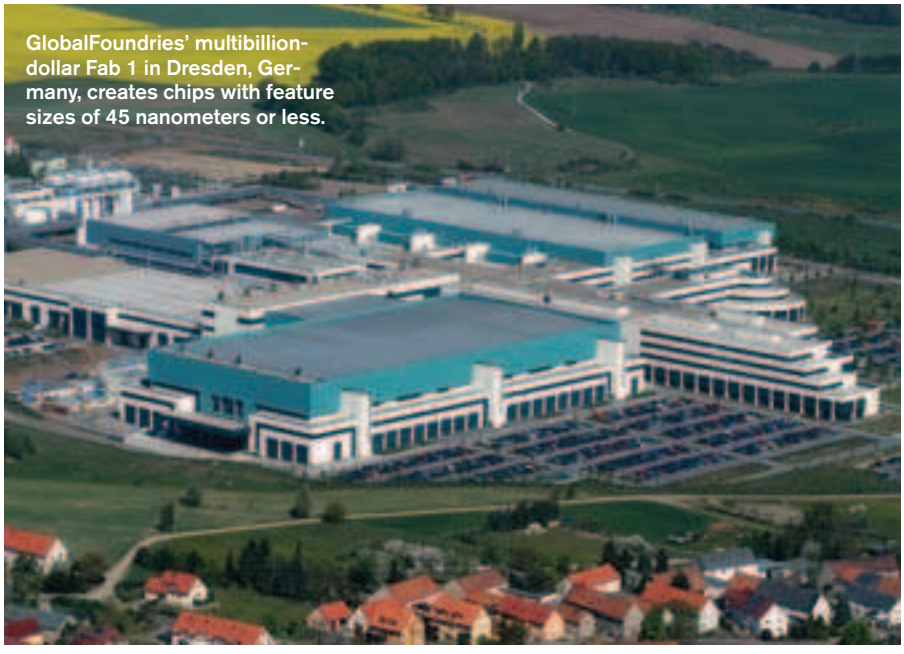
comm expects to have such chips in products next year.

Keeping tabs on what a processor is doing (or not doing) is critical to extending battery life. This summer, Intel will release the next generation of its mobile Atom processor, which will use a third to half as much power as a conventional chip when it's active and just a 50th as much power as when the device is idle.

In the short run, the drive to boost processor performance while saving energy will mean smart phones, netbooks, and tablets that work better and run longer on a single battery charge. And high-performance processors that require less energy may also change the way mobile devices are powered. The trickle of energy produced by a solar cell, or a piezoelectric device that converts the biomechanical energy of walking into electrical current, can't do too much for today's gadgets. But future mobile processors might get a significant boost from such energy sources. —*Katherine Bourzac*

For updates to this Briefing, take a snapshot of this code with software available at www.neoreader.com or visit **technologyreview.com/briefing**.

GLOBALFOUNDRIES



GlobalFoundries' multibillion-dollar Fab 1 in Dresden, Germany, creates chips with feature sizes of 45 nanometers or less.

INDUSTRY CHALLENGES

The High Cost of Upholding Moore's Law

A new leading-edge microchip fabrication facility, or fab, costs $3 billion to $5 billion to build. The high capital cost means that fabs must keep their production lines running at full capacity in order to pay back the money sunk into them. "The most expensive thing on the planet is a half-empty fab," says Brian Krzanich, general manager of Intel's manufacturing and supply chain. Consequently, only the highest-volume processor manufacturers—such as Samsung and Intel—are still sole owners and operators of state-of-the-art plants.

Other chip makers either produce lower-performance chips using older, less expensive techniques or outsource manufacturing to companies that specialize in operating semiconductor plants, such as GlobalFoundries (spun out of AMD last year) and the Taiwan Semiconductor Manufacturing Company. These foundries aggregate high-volume orders from multiple customers to keep production lines humming. GlobalFoundries, with more than $2 billion in annual revenue, expects to expand its annual production capability to 3.8 million wafers by 2014; each wafer will comprise hundreds of chips.

The most advanced mass-produced chips are made with integrated circuits whose

DATA SHOT

22 nanometers

The size of the smallest features that can currently be used in integrated circuits. Chips made with 22-nanometer technology should be on sale next year.

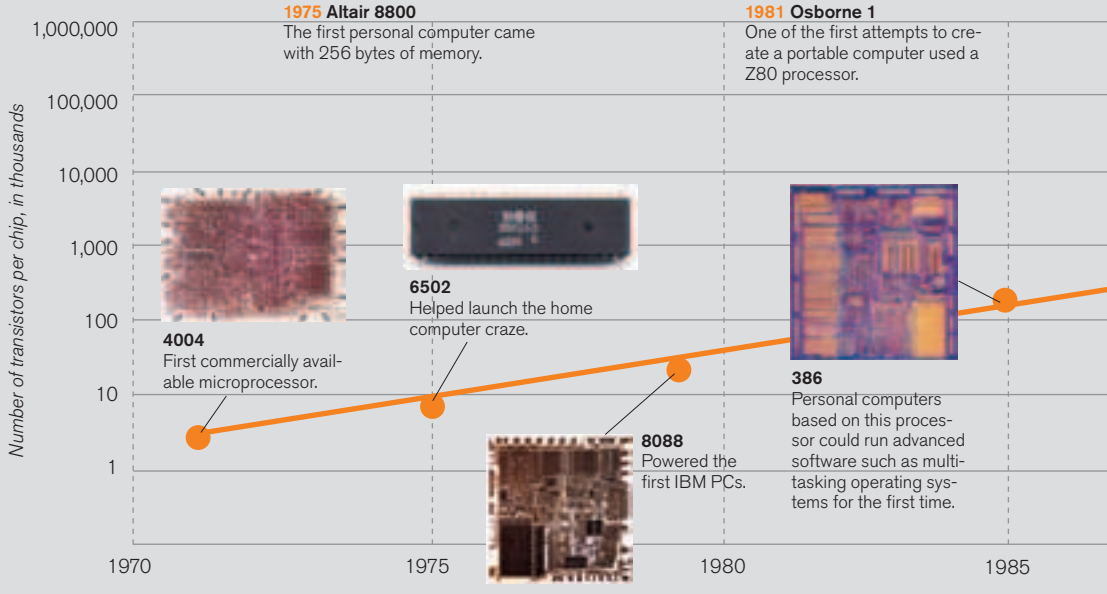
TIMELINE

March of the Machines

The growth in processor power over the last 40 years seems so uniform that it almost has the status of a law of nature. Moore's Law, as it is called, states that the number of transistors on a chip doubles every two years. We don't know how long it will hold true, but here are some of the most significant chips and devices this growth has made possible.







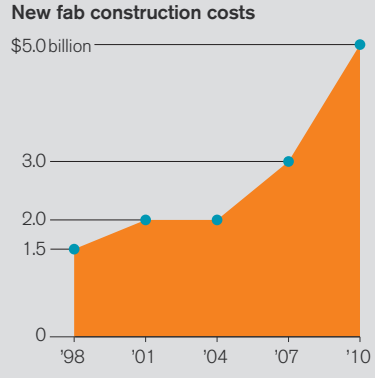
smallest features are about 32 nanometers across. The next generation, with 28-nanometer features, will arrive later this year, and 22- and 20-nanometer processors are "well down the path on development," says Ana Hunter, Samsung's vice president of foundry services in the United States. These smaller features mean that the constant gain in processor performance that has become familiar over the last 40 years can be expected to continue. Moore's Law—the prediction that the number of transistors on a chip will double every 24 months—will hold true for at least the next few years.

But as the elements on a chip become smaller, designing processors is getting tougher. All this means that R&D costs are rapidly increasing. In 2009, around $30 billion, or 17 percent of revenue, went to R&D across the industry—a 40 percent increase over 1999. Fabs are getting more expensive as well; in 1999, a state-of-the-art fab cost roughly $2 billion.

Chip makers are trying to contain costs with extensive collaborations. IBM, GlobalFoundries, STMicroelectronics, Toshiba, NEC, Infineon, and Samsung are all working together on developing high-volume manufacturing processes suitable for next-generation chips. Whether the shift toward multicustomer foundries and R&D cost-cutting will let Moore's Law continue into the next decade, however, is anyone's guess. In the end, the biggest limitation on silicon chip technology might not be the laws of physics but those of economics. —*Christopher Mims*

FABULOUSLY EXPENSIVE

The cost of new facilities is soaring.



Source: Intel

OVER THE HORIZON

Computing beyond Silicon

It is inevitable that eventually Moore's Law will fail—at least for silicon technology. Further miniaturizing silicon transistors to fit more of them on a microchip will become impossible, or at least too expensive. Researchers are anticipating that day by developing alternative materials such as gallium arsenide, graphene, and carbon nanotubes. The hope is that transistors made from these materials will be smaller, faster, and more energy efficient than anything that could ever be made from silicon. "We need to add more materials to the toolbox," says Michael Mayberry, director of components research at Intel.

One challenge is to make these materials work with the infrastructure built for silicon, which represents billions of

INTEL; DIRK OPPELT; SMITHSONIAN; TOMISLAV MEDAK



1984 Macintosh
Based on the Motorola 68000 processor, it was the first commercially successful computer to feature a graphical user interface.



1999 BlackBerry smart phone Made e-mail mobile for the first time.



2006 Playstation 3
A new generation of realistic games was made possible by the console's multicore Cell processor.



ARM6
ARM's low-power processor designs went on to drive nearly all the world's cell phones.



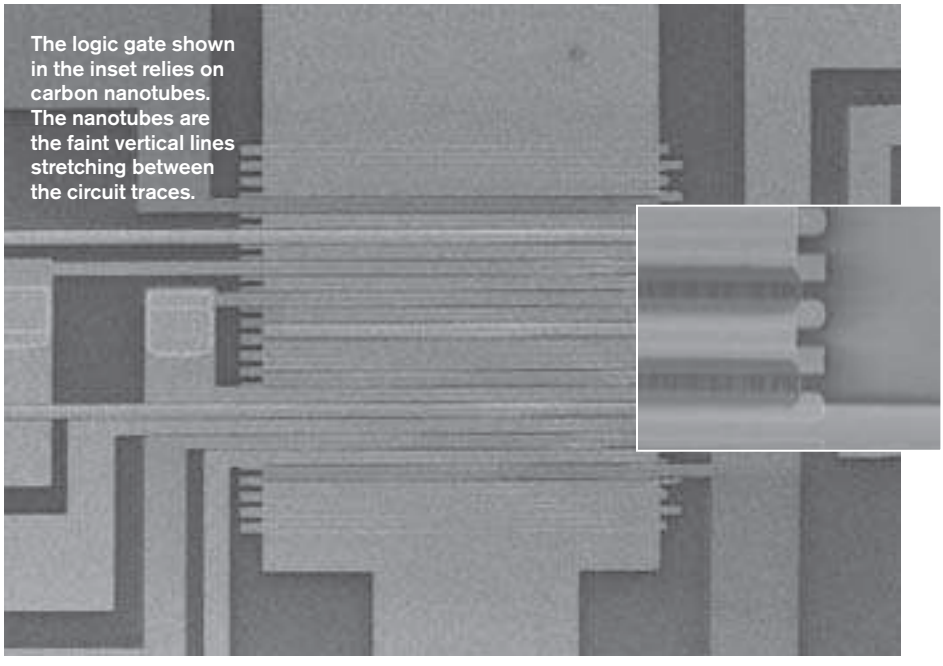
i7
A desktop processor running at 3.2 gigahertz, it boasts four or six computational cores.

1990 1995 2000 2005 2010

dollars in investment for chip makers *(see "The High Cost of Upholding Moore's Law," p. 71)*. Intel, for one, has developed expertise in compound semiconductors, such as gallium arsenide, that operate at higher speeds and lower voltages than silicon. But gallium arsenide is brittle, so devices made from it are difficult to manufacture in volume. Intel is trying to get around the problem by growing thin layers of this material on top of silicon wafers, hoping to improve silicon chips by adding a few high-performance gallium arsenide elements.

Other major contenders to replace silicon are based on carbon. In February, IBM made transistors from graphene, a one-atom-thick mesh of carbon; they are much faster than silicon transistors, switching at the rate of 100 gigahertz. Crucially, the IBM researchers built the transistor arrays on wafers, using a manufacturing-friendly process. These graphene transistors are still much bigger than their silicon counterparts, however, and an integrated circuit hasn't been made from them yet.

Researchers are also working on making transistors from carbon nanotubes. Like the graphene transistors, these are speedy, but they are much smaller. At Stanford University, scientists are developing techniques for fabricating three-dimensional integrated circuits based on these cylindrical molecules of carbon.



The logic gate shown in the inset relies on carbon nanotubes. The nanotubes are the faint vertical lines stretching between the circuit traces.

It's still uncertain what will ultimately replace silicon. But this once dominant material is already looking too fragile, too power hungry, and too expensive to drive our computers forever. *—Katherine Bourzac*

LUKE JONES; ARM LTD.; RESEARCH IN MOTION; SONY; INTEL; NISHANT PATIL, ALBERT LIN, HAI WEI, STANFORD UNIVERSITY



This RF bar code was printed with silicon ink. It can store 128 bits of data and transmit them at 106 kilobits per second.

CASE STUDY

Printing a Path to Success

Being a semiconductor startup in Silicon Valley is tough: to compete with established firms, you need tens of millions of dollars in initial investments and lots of time to commercialize your technology. Such is the situation facing Kovio, a startup based in Milpitas, CA. Founded in 2001 with technology spun out of MIT, Kovio makes chips by printing silicon circuits onto flexible paper-thin sheets of metal instead of etching them into rigid substrates using conventional lithography. Silicon particles are suspended in a liquid, and ink-jet printers deposit it in patterns on metal foils. The result is cheaper than traditional circuits and faster than printed organic electronics. And flexible chips could lead to new products, such as roll-up display screens.

For most of its history, Kovio's scientists and engineers focused on fine-tuning the printing process while its executives scoured various markets for a killer application. In 2008, the company announced its first product: printable RFID tags to replace the bar codes used to label products and the magnetic strips found on public-transit fare cards.

Today, the RFID market is worth about $5.6 billion. But it has yet to realize its potential, says Kovio CEO Amir Mashkoori, because conventional chips are too expensive. Today's tags can be as cheap as 15 cents each, but it doesn't make economic sense to slap a 15-cent tag on a $1 bottle of soda. Kovio's technology, Mashkoori says, can print RFID tags for a fraction of the price of conventional tags. That could promote wider use and give the company the revenue it needs to expand into different product categories, such as displays.

Because of the recession, the past couple of years have been financially tense for the company. Even so, last year it was one of the top-funded semiconductor companies in Silicon Valley. (In total, more than $80 million has been pumped into the business.) Companies worldwide are evaluating its RFID technology, and Kovio recently announced a licensing agreement with chemical supplier Nissan Chemical Industries that could lead to printed displays. Product availability is expected to be announced later this year. —*Kate Greene*

RESEARCH TO WATCH

Multicore Processors Create Software Headaches

For decades, improving processor performance meant cranking up a chip's clock speed. The payoff was immediately obvious to users: applications ran faster. But a faster chip consumes more electricity, draining batteries dry in mobile devices. Consequently, chip makers moved to energy-saving multicore designs, where multiple low-power processors on a single chip combine to replicate the performance of a single, faster processor *(see "Designing for Mobility," p. 70)*.

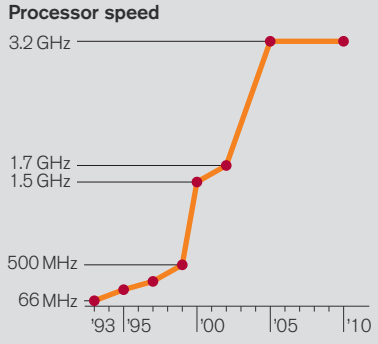
Unfortunately, applications on multicore systems don't get faster automatically as cores are added. Software has to be written to take advantage of the parallel processing power. And writing programs that run efficiently and stably across multiple cores is hard. Unless we solve this programming problem, says Prith Banerjee, Hewlett-Packard's senior vice president of research, users won't see any speed advantage in new microprocessors. Banerjee adds, "This is a very fundamental problem."

A promising potential solution is to take human programmers out of the loop as much as possible: rather than have individual programmers work out how to make their applications run across two, four, or more cores, the messy details could be left to compilers, the software used to convert

KOVIO

EASING OFF THE ACCELERATOR

Processor speeds have plateaued at a little above 3.2 gigahertz.



Source: Intel

high-level programming languages into the machine code a computer can understand. All the major software and chip companies, along with many academic researchers, are working to develop compilers that can handle such tasks. The biggest obstacle is that it's difficult to identify the parts of a program that don't depend on other parts, so that a core won't be left idle while it waits for some piece of data. Simply persuading developers to write cleaner programs, with well-defined interfaces between blocks of code, would make the job much easier, says Wen-mei Hwu, a professor of electrical and computer engineering at the University of Illinois. But he estimates that it will be five years before multicore-friendly compilers and matching programming practices diffuse through the computer industry. *—Stephen Cass*

DATA SHOT

8.2 gigahertz

The current speed record for a desktop microprocessor, achieved by enthusiasts who "overclocked" a chip designed to run at three gigahertz. To prevent the chip from melting, it was cooled with liquid nitrogen.

CHINA

A New Processor for a New Market

China represents a huge, and still largely untapped, market for computer makers: in a country of 1.3 billion people, only 40 million computers were bought in 2008, when the 300 million people living in the United States bought 66 million. As Chinese incomes rise and computer ownership grows, chip makers that establish themselves now will reap vast profits and dominate the market for years. Currently, China depends on Intel, ARM, and other Western companies for the CPUs that power its digital infrastructure, but the Chinese government is determined that a homegrown alternative will share in the spoils.

China's ambitions hang on a state-sponsored project, started in 2001 at the Institute of Computing Technology in Beijing, aimed at developing a family of indigenous processors that can be used in everything from cheap netbooks to supercomputers. To save costs, the chips are made using older silicon technologies and are based on an architecture invented in 1981 and owned by MIPS Technologies, based in Sunnyvale, CA. China chose to license an existing architecture because creating a new one would have meant reinventing the extensive software libraries that programmers need to create applications, not to mention educating the programmers themselves. The Chinese have surrounded the basic MIPS design with their own subsystems, adding instructions in recent versions so that the chips can run software written for the x86 processors that Intel and AMD make for personal computers.

The chips are commercially manufactured outside China by Geneva-based STMicroelectronics *(see "Companies to Watch," p. 77)* under the trade name Loongson. They already appear in cheap netbooks and desktop PCs. If China succeeds in making Loongson chips an alternative to Intel- and AMD-based systems in its emerging market, the implications could be felt throughout the developing world, with its billions of potential customers, for decades to come. *—Christopher Mims*

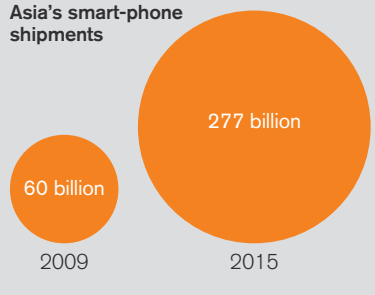


LEMOTE

This netbook from Lemote, based in Changshu City, China, uses a 900-megahertz Loongson chip and runs the Linux operating system.

ASIA GETS SMART (PHONES)

Sales of advanced phones will soar.



Source: IMS Research

MARKET WATCH

Mobile Chips Threaten High-Performance Manufacturers

At the end of 2009, Intel was shipping about 80 percent of all x86 processors—the type of chip that powers, for example, Windows-based personal computers. AMD accounted for nearly all the rest of the $28 billion market. But that market grew at a relatively modest rate of 2.5 percent last year, according to analyst firm IDC, restrained by lackluster sales of desktop computers.

Much of the real growth in microchips is coming from the explosion in mobile computing; netbooks and smart phones use both x86 and non-x86 chips. The challenges of designing chips for these devices, is rapidly redefining the industry, leaving Intel and AMD open to new competition.

In the past, the kinds of processors found in cell phones could not rival the performance of those found in personal computers. To surf multimedia websites or use a broad range of applications, you needed a laptop or desktop. Intel and AMD entrenched themselves in this market, where high barriers to entry contribute to profit margins that are higher than they are in the rest of the semiconductor industry: any potential competitor that wanted to make x86 chips for personal computers would have to sink billions into new fabs *(see "The High Cost of Upholding Moore's Law," p. 71).*

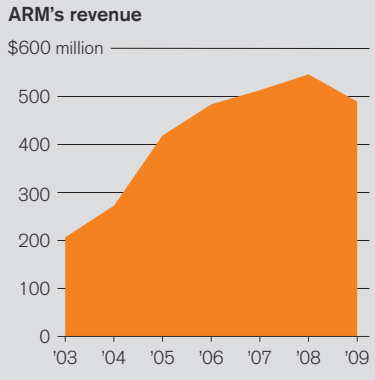
DATA SHOT

30.2 million

The number of netbooks sold in 2009—a 79 percent increase over 2008, according to Strategy Analytics.

RIDING THE WAVE

Mobile computing has boosted the fortunes of chip design firm ARM.



Source: Company filings

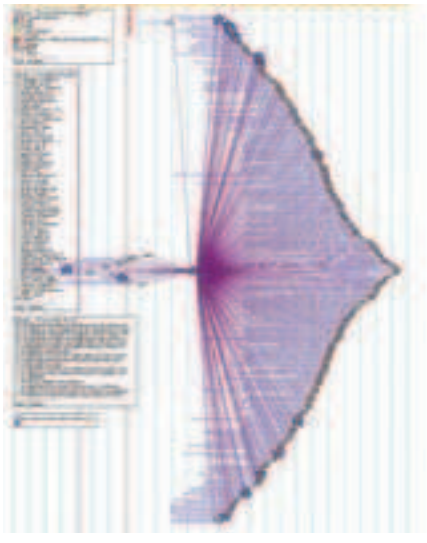
But mobile processors are now powerful enough to let a user stream video from the Internet or run any of thousands of applications. Especially worrying to Intel and AMD is the use of these mobile processors in ultracheap netbooks, which are exploding in popularity and stealing market share from x86-based laptops; IDC estimates that 14.5 million netbooks were sold in 2009, 110 percent more than in 2008.

The biggest threat to Intel and AMD comes from ARM, based in Cambridge, England. Instead of selling physical processors, ARM licenses designs to manufacturers. Licensees include Qualcomm, Samsung, Freescale, and Texas Instruments; ARM-based processors are found in more than 90 percent of the world's cell phones.

In the netbook market, chips based on ARM's designs compete directly with Intel's Atom processor, a stripped-down but power-efficient chip that Intel created in response to the inroads made by mobile processors. Broadly speaking, Atom processors offer more computational power than their ARM equivalents, but ARM chips draw less battery power than the Atom. However, some companies are attacking Atom's performance edge by combining ARM's designs with things like graphics processors for specific applications; the custom A4 chip that powers Apple's new iPad tablet is believed to run on an ARM core. Intel is responding this summer with a more power-efficient generation of the Atom. *—Christopher Mims*

INTELLECTUAL PROPERTY

Multicore Patents



IPVISION

Many microchips today incorporate multiple processing units, known as cores, to boost performance *(see "Designing for Mobility," p. 70).* These cores share system resources such as memory. Widely cited U.S. patent 5,617,537, awarded to Japanese communications giant NTT in 1997, arbitrates between cores as they access system memory, so that one core does not, for example, accidentally overwrite information that another core has placed in memory. *—Stephen Cass*

COMPANIES TO WATCH: PUBLIC

AMD

Makes graphics and processor chips for PCs

www.amd.com
Founded: 1969
Management: Dirk Meyer (CEO), Chekib Akrout (vice president, technology development)
Employees: 10,400
Revenues: $5.4 billion
R&D: $1.7 billion
Market cap: $5.8 billion

Technology: AMD makes processors based on the x86 instruction set; they are primarily used in laptop computers, desktop computers, and servers. In 2006, it acquired ATI, a maker of graphics chips and expansion cards, and since then, it has also made graphics processors for personal computers and games consoles, including the Nintendo Wii and Microsoft's XBox 360. **Market:** In 2009, AMD had 20 percent of the $28.6 billion market for global PC processor shipments. AMD graphics processors are used in more than half of all notebooks that rely on discrete graphics cards for gaming and other multimedia-heavy applications. **Strategy:** Faced with the rapidly growing capital costs of advanced chip manufacturing, AMD spun off its semiconductor manufacturing business in 2009 to form GlobalFoundries, owned equally by AMD and investors from Abu Dhabi. AMD has since concentrated on developing the graphics portion of its business. **Challenges and next steps:** In an attempt to differentiate its processors from Intel's, in 2011 AMD will launch a family of products that integrate a graphics processor and a CPU in a single chip. These devices will be aimed at improving performance in multimedia applications such as games and video.

ARM

Licenses designs for mobile processors

www.arm.com
Founded: 1990
Management: Warren East (CEO), Mike Muller (CTO)
Employees: 1,710
Revenues: $490 million
R&D: $169 million
Market cap: $4.6 billion

Technology: The company develops designs for the computational cores of low-power processors. Chip manufacturers license these designs, often combining them with their own integrated circuitry, to make custom "system on a chip" processors for applications such as communications or multimedia processing. **Market:** ARM licenses its technology to more than 660 companies, including manufacturers such as Samsung and Hewlett-Packard; 3.9 billion ARM-based processors were made in 2009. Such chips power more than 90 percent of the world's cell phones. **Strategy:** ARM is capitalizing on the boom in network-connected devices. In the mobile market, this means selling to makers of smart phones and netbook computers. Outside that market, the company is selling advanced chips to customers such as TV manufacturers looking to offer built-in Internet video streaming. **Challenges and next steps:** ARM and Adobe have worked together to optimize the performance of Adobe's popular Flash player (used to deliver multimedia on the Web) on ARM devices. Developing standardized software platforms while continuing to let licensees extensively customize ARM-based chips will remain a difficult challenge. ARM is also developing and licensing designs for the next generation of silicon devices.

IBM

Creates chips for embedded and server applications

www.ibm.com
Founded: 1896
Management: Samuel J. Palmisano (CEO), John E. Kelly (director of research)
Employees: 399,409
Revenues: $95.8 billion
R&D: $5.8 billion
Market cap: $166.7 billion

Technology: IBM owns several fabs that make processors for its own products, such as its mainframes, and also custom chips for other manufacturers. In addition, it operates laboratories around the world that do fundamental research into new semiconductor materials and designs for processors and memory chips. **Market:** IBM's processor technology is used in high-performance servers, in embedded applications (including technologies for the automotive and aerospace industries), and in the three major game consoles currently available (the Nintendo Wii, the Sony Playstation, and the Microsoft Xbox 360). **Strategy:** IBM is investing heavily in cloud computing, which can help mobile devices by using network connections to shift tasks to a remote data center if they are too computationally intensive for a mobile processor to handle. **Challenges and next steps:** In moving away from manufacturing commodity products such as laptops and disk drives in favor of higher-margin products that rely on advanced technologies, the company has increased the pressure on its research and development facilities to produce marketable results. It is investigating graphene and other materials as potential replacements for silicon in processors.

Intel

Dominant maker of processors for personal computers

www.intel.com
Founded: 1968
Management: Paul S. Otellini (CEO), Sean M. Maloney, David Perlmutter (general managers, Intel Architecture Group)
Employees: 79,800
Revenues: $35.1 billion
R&D: $5.7 billion
Market cap: $122.6 billion

Technology: The company makes x86 processors, which power laptop, desktop, and server processors. Its huge R&D program drives many of the advances that have doubled the number of transistors on a chip every two years for the last 40 years. To maintain gains in performance, Intel has focused for the last few years on developing chips with multiple processors. **Market:** Intel commands 80 percent of the $28 billion market for x86 processors, which run the popular Windows, OS X, and Linux operating systems. **Strategy:** Even as it continues to invest in cutting-edge chip manufacturing facilities and high-performance chips for servers and workstations, Intel is working to adapt to the growth in mobile computing; its low-power Atom processor is designed to compete with mobile processors based on designs from ARM. **Challenges and next steps:** With its new focus on building processors for the mobile market, it has had to make adjustments in its engineering culture—for example, learning not to include features that customers haven't requested. A more power-efficient next generation of the Atom processor is expected this year. For high-performance computers, Intel is ramping up the production of processors that use the smallest transistors currently feasible with mass production.

Qualcomm

Makes chips for mobile telecommunications

www.qualcomm.com
Founded: 1985
Management: Paul E. Jacobs (CEO), Roberto Padovani (CTO)
Employees: 16,100
Revenues: $10.4 billion
R&D: $2.4 billion
Market cap: $70.8 billion

Technology: Qualcomm specializes in chips for mobile telecommunications, manufacturing chips for makers of cell phones and other mobile devices and licensing technology to them. It has recently developed the Snapdragon chipset, which combines 3G network connectivity, multimedia processing, and an ARM-based processor for netbooks. **Market:** Qualcomm licenses its technology to more than 190 manufacturers worldwide. About 69 percent of the company's revenues come from customers based in South Korea, China, and Japan. **Strategy:** Between 2000 and 2007, Qualcomm's R&D spending rose by 525 percent; that spending now consumes 20 percent of revenues, double the earlier share. The company is investing heavily in developing products for wirelessly connected, multimedia-enabled mobile devices. **Challenges and next steps:** Qualcomm's 3G technology is based on the CDMA cell-phone standard, which faces competition from the GSM standard that is more widely deployed around the world. The company is now moving aggressively into emerging markets. For example, it is working with the three largest telecom operators in China to deploy CDMA 3G networks across the country, which will promote demand for handsets and notebooks that use the CDMA standard.

COMPANIES TO WATCH: PUBLIC

Samsung
Creates chips and consumer electronics

www.samsung.com
Founded: 1938
Management: Gee-Shung Choi (CEO), Hyung-Kyu Lim (president, Samsung Advanced Institute of Technology)
Employees: 164,600
Revenues: $120.6 billion
R&D: $6.2 billion
Market cap: $92.8 billion

Technology: Samsung makes processors for its own consumer electronic products and for other manufacturers; its high-performance chips are based on the ARM architecture. Its experience in combining the ARM design with low-power circuitry for a wide range of consumer applications differentiates it from other makers of ARM-based chips. **Market:** As well as making components for other electronics firms, Samsung sells its own brand of mobile devices, televisions, printers, telecommunications equipment, and appliances worldwide. It has the second-largest global market share in cell phones and is the world's leading producer of digital memory chips. **Strategy:** Samsung has chosen to retain its own state-of-the art semiconductor plants while most other electronics companies have spun off their manufacturing facilities. It has been able to closely tailor its processor designs to its line of memory chips as the memory market evolves. **Challenges and next steps:** The life cycle of consumer products is shortening; it is now about 12 to 18 months, putting pressure on Samsung to create ever higher-performance designs quickly. In response, it is building up its capability for in-house processor design.

Sony
Consumer electronics and media conglomerate

www.sony.com
Founded: 1946
Management: Howard Stringer (president and CEO)
Employees: 171,300
Revenues: $83.3 billion
R&D: $5.4 billion
Market cap: $36.7 billion

Technology: Sony sells a number of processors for embedded applications in consumer electronics. Its most ambitious is the Cell, which is used in the Sony Playstation 3 game console. Developed in partnership with IBM and Toshiba, the Cell marries a general-purpose processor with eight specialized ones that can process large amounts of multimedia data in parallel, making it ideal for games and video applications. **Market:** Sales of Sony's semiconductor devices are expected to reach $5.4 billion for FY 2009. Playstation 3 sales are also a highlight for a company that has been hit by the downturn in spending; 13 million units were sold in FY 2009. **Strategy:** The company develops mobile electronics through Sony Ericsson, a joint venture with the Swedish telecommunications giant. For its Playstation 3 console, Sony has increased its profit margins by consistently improving the chip's manufacturing process. **Challenges and next steps:** Sony is struggling with the effects of the recent recession; after a companywide reorganization, it plans to close 10 percent of its manufacturing sites and has reduced R&D spending 10 percent as well. It is now placing increased emphasis on creating network-friendly hardware, an area in which it has lagged in the past.

STMicroelectronics
Makes chips for embedded applications

www.st.com
Founded: 1987
Management: Carlo Bozotti (president and CEO), Jean-Marc Chery (CTO)
Employees: 50,000
Revenues: $8.5 billion
R&D: $2.4 billion
Market cap: $8.6 billion

Technology: The company combines flash memory and other supporting hardware with ARM-based processors to create embedded microcontrollers for a range of devices. It also develops high-performance processors for multimedia devices such as digital televisions and set-top boxes. ST maintains its own manufacturing plants, but in the last few years it has allowed its designers to use outside fabs when needed. **Market:** Sells to a wide range of markets, including those for medical devices, industrial and automotive applications, and consumer electronics. **Strategy:** ST identifies customers that it believes are likely to create or exploit new market trends. It then offers to work closely with those customers, tailoring products to meet their needs. When a trend takes off, these products are sold to later entrants looking for technologies optimized for that market. The company works closely with ARM to develop more power-efficient processor designs. **Challenges and next steps:** STMicroelectronics' main challenge is to differentiate its offerings from other ARM-based chips. It is focusing on improving energy efficiency, developing touch sensors and low-data-rate wireless devices, and making products for automotive applications.

Texas Instruments
Combines processors with digital signal processors

www.ti.com
Founded: 1930
Management: Rich Templeton (CEO), Kevin Ritchie (vice president, Technology and Manufacturing Group)
Employees: 26,584
Revenues: $10.4 billion
R&D: $1.5 billion
Market cap: $30.6 billion

Technology: TI makes ARM-based processors that can be combined with the company's broad family of wireless chips and digital signal processors. The highest-performing systems are aimed at handling mobile video and audio. In recent years the company has also made substantial investments in analog chips. **Market:** Apart from calculators, TI makes no end-user products of its own. Instead, it sells analog and digital components—particularly chips for cell phones and other wireless devices—to other electronics manufacturers worldwide. **Strategy:** TI has been expanding its sales into China, India, and Eastern Europe; developing its line of products with embedded processors for markets such as electric vehicles; and adapting its wireless products so that instead of simply handling telecommunications tasks, such as interfacing with a cell-phone network, they can enable multimedia and other software applications. **Challenges and next steps:** The recession of 2008 and early 2009, followed by unexpectedly strong demand in the last three quarters of 2009, led to difficulties coördinating supply and demand. The company plans to continue developing its processor line as a key element in its growth strategy.

Toshiba
Diversified equipment and chip maker

www.toshiba.com
Founded: 1875
Management: Norio Sasaki (CEO), Shozo Saito (president and CEO, Toshiba Semiconductor)
Employees: 199,000
Revenues: $71.7 billion
R&D: $4.1 billion
Market cap: $17.2 billion

Technology: Toshiba partnered with Sony and IBM to create the Cell processor but struggled to find a consumer product for it. In January, it finally announced a television that can convert 2-D video to 3-D in real time. In the meantime, the company has been using elements of the Cell's technology in a range of chips designed to process high-definition video. **Market:** In addition to marketing its own consumer and industrial products (it is a leading manufacturer of personal computers), Toshiba sells components to other electronics makers. Sales in digital media products, such as televisions, have helped offset a slump in demand for PCs. **Strategy:** The company is concentrating capital investment on notebooks and mobile devices, among a few key areas. It has also improved its semiconductor manufacturing technology, allowing substantial reductions in costs. **Challenges and next steps:** The recession has forced Toshiba into an extensive reorganization, and its R&D budget was cut 20 percent from FY 2008 to FY 2009. The company is still pushing to cut semiconductor manufacturing costs, turning to overseas production as well as establishing joint ventures with other companies in Japan. It also plans to expand sales into emerging countries.

Advances in Nanotechnology

In just the last few years, the number of products on the market that incorporate nanoparticles has exploded. According to the Project on Emerging Nanotechnologies, more than a thousand nano-based consumer products are now available, compared to only 212 in March, 2006. Lux Research predicts that nanotechnology will generate $2.5 trillion in 2015.

Specks of Gold

Gold, prepared to the nanoscale, has properties that attract scientists hoping to diagnose and treat diseases. Qun Huo, chemist at the University of Central Florida, first turned her sights on using gold to create an inexpensive test for prostate cancer. In 2009, according to the American Cancer Society, there were almost 200,000 new diagnoses of prostate cancer, the most common form of cancer among American men.

What intrigued Huo, she says, are gold's optical properties at the nanoscale. Gold becomes dark burgundy, and it absorbs and scatters light well. Huo, however, was particularly interested in scattering.

She partnered with researchers at the M.D. Anderson Cancer Center in Orlando to develop a new test for prostate cancer detection based on these principles. The team coated gold nanoparticles with antibody molecules. These recognize and bind with specific target proteins in the sample and thus increase the particle size. With a dynamic light-scattering instrument, Huo can search for the enlarged proteins in small samples such as a drop of blood. While PSA tests are used today to detect prostate cancer, this new test is intended to increase the accuracy of tests for early detection.

"Basically, these nanoparticles are a hook," says Huo. "When you're fishing, you can feel it get heavy. And in my case, I'm able to see that the nanoparticle becomes bigger, that it caught something." She believes this test could be available within a few years.

Tools for the Trade

One of the challenges in developing nanoscale techniques and materials is ensuring the accuracy of the tools. Sarasota-based DTI is attempting to solve this challenge, offering high-precision devices for companies and researcher centers. DTI designed an ultrasonic piezomotor to manipulate and position objects at the nanoscale. It functions by means



of a special ceramic ring that pulses at ultrasonic speed in response to pulses of electricity, which causes precise rotations of the motor. The result is a device that is both faster than a conventional electromagnetic motor and offers a resolution over a thousand times higher.

Says DTI's CEO Mark Broderick, "We're enabling our customers to manipulate a sample or procedure at the submicron level, so the applications are very broad." One of the tools, a piezoelectric nanomanipulator, can be controlled by a joystick or a computer. A push of the joystick button allows researchers to penetrate a cell membrane without damaging the cell.

Ensuring Safety

Brij Moudgil, director of the University of Florida's Particle Engineering Research Center (PERC), relates how when center researchers began studying applications of nanoparticles in biomedicine more than a decade ago, they kept returning to safety questions. "What happens to the particles in the body once they've done their job? What is their fate?" asks Moudgil.

The center has been developing tools and protocols to learn quickly, in the early stage of particle research, whether the particle will be toxic to cells or instigate a disease. They've been developing tools, together with local and national companies, to obtain reliable toxicity pathway information in a rapid manner; such tests today are time-consuming and expensive. "We don't want to spend one year to develop [a new particle] and then another 9 months to find out whether it's toxic," says Moudgil.

The toxicity screening process involves bringing the particle close to a single cell and investigating how it affects cellular functions. The process can then be scaled up and used to test colonies of cells. The goal is to provide researchers and companies around the country with tools to avoid toxicity at the earliest stages of development. "We want to know how we can reduce costs and get reliable information early on," Moudgil adds.

Download the *Advances in Nanotechnology Paper* to learn more about:

- Nano-based filters that clean water to the billionth
- New conductive composites for aerospace
- Fuel-cell storage based on nanopores

COMPANIES TO WATCH: PRIVATE

Arteris
Faster on-chip communications

www.arteris.com
Founders: Alain Fanet, Philippe Boucard, Cesar Douady
Management: K. Charles Janac (CEO), Philippe Martin (CTO)
Funding: $37.3 million
Key investors: ARM, Ventech, TVM Capital, Synopsys, Innotech, Docomo Capital (NTT Docomo), Crescendo Ventures

Technology: Many chip makers are developing specialized chips for specific applications, especially in mobile computing—an audio processor could be combined with a CPU for a digital music player, for example. Arteris creates network-on-chip (NoC) designs, which enable these different subsystems to communicate with each other quickly and efficiently. **Market:** The company markets its fast, integrated chip design to the multimedia, telecom, and mobile industries. The technology sold by Arteris is used by companies like Texas Instruments, NEC, and Pixelworks, a semiconductor company that makes chips for high-end display systems such as projectors and large-screen flat panels. **Strategy:** Arteris targets customers building specialized "system on a chip" integrated circuits for applications where a general-purpose processor would be too slow or expensive. **Challenges and next steps:** With $9.7 million from recent deals with Qualcomm and ARM, the company plans to expand its global marketing and increase the amount of customer support it offers. It is also developing a more streamlined architecture that will offer higher performance at lower power and automated tools that will make it easier to integrate Arteris's designs into chips.

D-Wave Systems
Developing quantum computers

www.dwavesys.com
Founders: Geordie Rose, Haig Farris, Bob Wiens, Alexandre Zagoskin
Management: Vern Brownell (CEO), Geordie Rose (CTO)
Funding: Over $60 million
Key investors: International Investment and Underwriting, Harris and Harris Group

Technology: In theory, a full-fledged quantum computer could perform in seconds or minutes tasks that would take even the most powerful supercomputer millions of years, but progress is currently slow. In the interim, D-Wave is developing a new kind of high-performance computing system: an adiabatic quantum-computing processor. The processors use superconducting metals instead of semiconductors, to take advantage of quantum effects that can reduce time and memory for heavy computing. **Market:** The company targets areas where quantum computing would help with large amounts of complex data, such as science, finance, and cryptography. (Modern cryptography relies largely on mathematical operations that are easy to do but difficult to reverse, such as multiplying two very large prime numbers—which is considerably simpler than determining the two prime numbers from the product alone.) **Strategy:** Its goal is to supply infrastructure to national labs, corporate research centers, and other institutes that do cutting-edge research. **Challenges and next steps:** The company hopes to create the first commercial quantum computers that will be able to operate quickly and supplement digital computers, but it has faced skepticism about some of its technical claims.

Everspin Technologies
Magnetic memory chips

www.everspin.com
Founders: Spun out of Freescale Semiconductor in 2008
Management: Aurangzeb Khan (CEO), Saied Tehrani (COO)
Funding: $30 million
Key investors: Sigma Partners, Draper Fisher Jurvetson, Epic Ventures, Freescale Semiconductor

Technology: Everspin makes magnetoresistive random-access memory (MRAM) chips. Each cell consists of two magnetic elements on top of a transistor; flipping the spins of electrons in one of the magnetic elements so that it is or is not aligned with the other element stores a *0* or a *1*. Data stored in MRAM is nonvolatile. The technology improves on flash memory in that it doesn't limit the number of times a cell can be written to, and each write cycle is a million times faster. **Market:** Freescale brought the first MRAM chips to market in 2006, before the technology was spun off. Everspin has subsequently targeted storage systems and industrial applications such as robotics, where the stability of data over time is critical. **Strategy:** The company doesn't have much of a hold in the consumer market because MRAM is more expensive than other types of nonvolatile memory, including flash. It is trying to lower its prices to be more competitive in this market. **Challenges and next steps:** MRAM costs more because the storage density is lower than that of other technologies: fewer bits can be stored per chip. Everspin is developing a new technology for reading and writing to its memory cells that will allow higher-density chips.

Kovio
Printing circuits with silicon ink

www.kovio.com
Founder: Founded by Joseph Jacobson in 2001
Management: Amir Mashkoori (CEO), Vik Pavate (VP of business development), Jiang Li (VP of engineering)
Funding: Over $80 million
Key investors: Bessemer Venture Partners, Kleiner Perkins Caufield and Byers

Technology: Kovio's silicon inks can be used to print RFID tags, transistors, and other analog and digital electronics using ink-jet printing. These devices don't match the performance of conventional silicon electronics, but they're much cheaper to make. **Market:** Kovio's first product is printed RFID tags for inventory control and mass-transit passes. Currently, RFID tags cost about 15 cents apiece, and the company thinks it can significantly undercut this price. That would open up new applications for which today's RFIDs are too expensive, such as tracking individual products in retail stores. Kovio is also targeting the display market by developing circuits for flexible screens. **Strategy:** In February, Kovio partnered with Nissan Chemical Industries to ramp up production of silicon inks and to develop display applications. **Challenges and next steps:** Kovio's next generation of RFID tags, which the company expects will come to market in 2011, will have more memory and better security features. The company says its work on RFIDs has laid the groundwork for a move into printed transistor arrays. In that market, Kovio will face competition from other companies developing materials for flexible circuits such as Plastic Logic.

Luxtera
Connecting chips with light

www.luxtera.com
Founders: Alex Dickinson, Cary Gunn, Axel Scherer, Eli Yablonovitch
Management: Greg Young (CEO), Cary Gunn (CTO)
Funding: $72.8 million
Key investors: New Enterprise Associates, Sevin Rosen Funds, August Capital, Freescale Semiconductor

Technology: Luxtera designs silicon photonics—optical circuits that are fully integrated with electronics and made using standard microchip manufacturing techniques. The devices are less expensive and orders of magnitude smaller (and thus in many cases faster) than traditional photonic elements. The company currently makes a high-speed optical cable for connecting servers, and late last year it announced an optical transceiver that makes it possible to send data between chips at 10 gigabits per second. **Market:** The company's optical interconnects are designed for use in supercomputing clusters, telecommunications equipment, and large data centers. Its optical cables can be used over longer distances than previous high-performance interconnects, while its new chips will make optical data transmission possible with high-performance computers. **Strategy:** Luxtera is focused on high-performance systems that need to send and receive data very quickly. **Challenges and next steps:** The company has just begun its efforts to expand its silicon photonics business beyond data-center products. It faces cash management and marketing challenges that are typical to any technology business, and efforts to bring optical networking to the chip level will bring Luxtera into competition with Intel.

Technology Review's Career Resources

Program Directory

NYU·poly
POLYTECHNIC INSTITUTE OF NYU

EXECUTIVE MASTER'S PROGRAMS IN TECHNOLOGY MANAGEMENT

Polytechnic Institute of NYU Executive Master's Programs
Based in New York City and Westchester, NY, Polytechnic Institute of NYU's fast-track executive master's programs in Management of Technology and Information Management enable professionals to move beyond pure technology and become effective managers of innovation. Participants gain knowledge that is increasingly valuable to firms and not easily outsourced. Join us for an info session and get complete details at: **http://www.mot-im.poly.edu**

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MIT Professional Education—Advanced Study Program
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www.technologyreview.com/careerresources/

Career Growth Profile



Irene Poh
Age: 28
Job Title: Senior Business Analyst
Employer: Procter and Gamble.
Bachelor's degree in policy analysis and management, Cornell University
Master's degree in research and industrial engineering, Cornell University
MBA, University of Chicago

Like most undergraduates, Irene Poh wasn't sure what she wanted to be "when she grew up." One thing she did know, however, was that she was a "quant at heart." Quantitative subjects such as mathematics and statistics spoke to her. Poh felt strongly that her career would draw upon her passion for analysis.

Today, at age 28, she is a senior business analyst for Procter and Gamble, providing advisory and consulting services to P&G hair-care marketing teams across North America.

"I work with the various business leaders to provide strategic and tactical recommendations on how to solve some of their highest-priority business problems," Poh explains. "My prior roles at P&G have included global supply-chain consulting, which was more pure operations research and industrial engineering work; I also was a manager at one of P&G's largest warehousing operations in the world."

Not bad for a woman who has yet to stick 30 candles in her birthday cake.

Poh attributes her solid footing in both qualitative and quantitative skills to her bachelor's degree in policy analysis and management and her master's degree in research and industrial engineering from Cornell University.

"Both degrees are about solving difficult programs and influencing decision makers and/or policy makers at critical moments," says Poh, who says her master's degree also helped her command a higher starting salary when P&G hired her straight out of school.

Three years into her career, however, Poh decided she needed more schooling, and a master's degree in business administration seemed to fit the bill.

To learn more about Irene's decision to continue her education—and how it helped her move up the corporate ladder, visit www.technologyreview.com/careerresources/.

To list your program or recruitment ad in our Career Resources section, e-mail Barry Echavarria at barry.echavarria@technologyreview.com or call 603-924-7586.

COMPANIES TO WATCH: PRIVATE

Nantero
Using nanotubes to store data

www.nantero.com
Founders: Founded by Greg Schmergel, Thomas Rueckes, and Brent Segal in 2001
Management: Greg Schmergel (CEO), Thomas Rueckes (CTO)
Funding: $31 million
Key investors: Charles River Ventures, Draper Fisher Jurvetson, Stata Venture Partners, Harris and Harris Group

Technology: Nantero is developing very dense nonvolatile memory chips based on carbon nanotubes. Nanotubes that make up a coating on a silicon wafer can be individually charged by the application of an electrical current. When it has a positive surface charge, a nanotube on such an array will bend up to make contact with a negatively charged metallic electrode. Switching each nanotube or bit from a bent to unbent state, representing *0* or *1*, takes picoseconds and very little power. The nanotubes won't move until their charge state is altered, which means these devices should be very stable over time. **Market:** Nanotube-based nonvolatile random-access memory (NRAM) could compete with a range of memory technologies, including flash and computer hard disks. **Strategy:** Nantero has partnered with ON Semiconductor, Lockheed Martin, and other manufacturers to prototype and test its chips. The company will license the memory technology to other companies and expects it to be on the market in less than five years. **Challenges and next steps:** Getting a new memory chip into production is a tremendous undertaking. If it succeeds, Nantero wants to develop other applications for its carbon nanotubes, including integrated circuits.

Numonyx
Nonvolatile phase-change memory

www.numonyx.com
Founders: Spun out of STMicroelectronics and Intel in 2008
Management: Brian Harrison (CEO), Edward Doller (CTO)
Funding: $150 million
Key investors: Francisco Partners

Technology: Numonyx is developing nonvolatile phase-change memory. Its memory cells include a small piece of glassy material that can switch between an amorphous and a polycrystalline state to store information; the amorphous state has high electrical resistance, while the polycrystalline state has low electrical resistance. Writing to a memory cell takes about the same time as it does with flash memory, but unlike flash, phase-change memory can be read as quickly as the volatile dynamic RAM used in computers. **Market:** Phase-change memory could tap the same markets as flash memory: it could be used in memory cards, mobile phones, and navigation systems and as additional storage for computers. **Strategy:** Numonyx hopes to develop phase-change memory into a technology that can be used as general-purpose computer RAM; users could turn a laptop with such a memory completely off, saving battery power, and then turn the computer back on to pick up right where they left off. **Challenges and next steps:** In February, memory company Micron announced that it would acquire Numonyx for $1.27 billion in stock, pending regulatory approval. The sale should be completed within the next few months.

Plastic Logic
Organic transistor products

www.plasticlogic.com
Founders: Founded by Stuart Evans, Richard Friend, and Henning Sirringhaus in 2000
Management: Richard Archuleta (CEO), Martin Jackson (VP for technology)
Funding: $200 million
Key investors: Dow Venture Capital, BASF Venture Capital, Siemens Venture Capital

Technology: Plastic Logic's e-reader, the Que, is the first to use transistors based on organic polymers rather than silicon. Organic transistors make it possible to use a plastic backing instead of glass, resulting in a reader that's thin, lightweight, and extremely durable. While the Que's screen is not flexible, the technology can be used to drive flexible displays. **Market:** In the market for e-readers—which is a booming but crowded field—Plastic Logic's differentiates itself with its letter-page-size screen, which makes it a good choice for reading documents and magazines. It can also display e-mail and calendars from Microsoft Exchange. **Strategy:** Plastic Logic has targeted business users to differentiate the Que from other e-readers, such as Amazon's Kindle and the Sony Reader. The company has partnered with U.S. book retailer Barnes and Noble to provide content. **Challenges and next steps:** It's unclear whether the Que will be the first of many products based on organic transistors or a one-off. The company has had to develop its printing processes from the ground up, because there aren't any companies manufacturing such equipment. This means that even if the Que is a success, Plastic Logic may have difficulty scaling up.

Samplify Systems
Improving communication chips

www.samplify.com
Founder: Founded by Al Wegener in 2006
Management: Tom Sparkman (CEO), Al Wegener (CTO)
Funding: $11 million
Key investors: Charles River Ventures, Formative Ventures

Technology: Samplify has developed a signal compression algorithm that can be incorporated into analog-to-digital converters to reduce the bandwidth needed in wireless communications and medical-image acquisition. As the explosion in network-connected mobile computing gobbles up the radio spectrum, such compression techniques will be vital to delivering high-quality multimedia without causing network congestion or consuming the relatively limited storage on mobile devices. **Market:** The company licenses its designs and algorithms to wireless manufacturers and semiconductor companies that make analog-to-digital conversion chips for defense, imaging, industrial, and communications applications. **Strategy:** Samplify is maintaining its focus on the wireless and medical-imaging markets. It hopes to take advantage of the growth in mobile computing by making it cheaper to build the base stations that will make up the backbone of growing 4G data networks. **Challenges and next steps:** The company plans to expand into new markets, including defense applications, where its compression algorithms could save money by decreasing the amount of intelligence data that needs to be stored for subsequent analysis.

Tilera
Makes chips with many cores

www.tilera.com
Founders: Anant Agarwal, Vijay Aggarwal, Devesh Garg
Management: Omid Tahernia (CEO), Anant Agarwal (CTO)
Funding: $64 million
Key investors: Bessemer Venture Partners, Columbia Capital, Quanta Computers, Walden International, Broadcom, Quanta Computer, NTT Finance

Technology: Tilera makes multicore computer chips that link large numbers of processing units in a type of mesh network. This network allows each core to share information with other processors on the chip more easily and quickly than is possible with an on-chip bus interconnect (a sort of central intersection through which data must flow to travel between the cores of a traditional multicore chips). Last October, the company announced that it had built the world's first 100-core chip. **Market:** Tilera's 64-core chip has been used in cellular towers, graphics processing, videoconferencing systems, Internet Protocol–based TV systems, and hardware that monitors Internet traffic to reduce spam and viruses. Its newest chip is aimed at the high-profit server market. **Strategy:** Tilera plans to compete with Intel and AMD in selling server chips. Its newest chip is designed for high-end networking and telecommunications; it should ship later this year. **Challenges and next steps:** Tilera's biggest difficulty will be continuing to find markets that require extremely high CPU performance and also benefit from parallelization. However, the growth of mobile data networks and cloud computing offers the company opportunities.

What's the fastest way to learn a language?

ACT LIKE A BABY.

It's not the advice you'd expect. Learning a new language seems formidable, as we recall from years of combat with grammar and translations in school. Yet infants begin at birth. They communicate at eighteen months and speak the language fluently before they go to school. And they never battle translations or grammar explanations along the way.

Born into a veritable language jamboree, children figure out language purely from the sounds, objects and interactions around them.

Their senses fire up neural circuits that send the stimuli to different language areas in the brain. Meanings fuse to words. Words string into structures. And language erupts.

Three characteristics of the child's language-learning process are crucial for success:

First, and most importantly, a child's natural language-learning ability emerges only in a speech-soaked, immersion environment free of translations and explanations of grammar.

Second, a child's language learning is dramatically accelerated by constant feedback from family and friends. Positive correction and persistent reinforcement nurture the child's language and language skills into full communicative expression.

Third, children learn through play, whether it's the arm-waving balancing act that announces their first step or the spluttering preamble to their first words. All the conversational chatter skittering through young children's play with parents and playmates—"…what's this…" "…clap, clap your hands…" "…my ball…"—helps children develop language skills that connect them to the world.

Adults possess this same powerful language-learning ability that orchestrated our language success as children. Sadly, our clashes with vocabulary drills and grammar explanations force us to conclude it's hopeless. We simply don't have "the language learning gene."

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REVIEWS

MEDIA

Going Out of Print

THE NEW GENERATION OF E-BOOK READING GADGETS WILL TRANSFORM THE TROUBLED BOOK, MAGAZINE, AND NEWSPAPER INDUSTRIES. BUT IT'S UNCERTAIN WHAT THAT TRANSFORMATION WILL LOOK LIKE.

By WADE ROUSH

For serious readers, products like Amazon's Kindle 2, Barnes and Noble's Nook, and Sony's Daily Edition are a godsend. It's not just that these electronic reading devices are handy portals to hundreds of thousands of trade books, textbooks, public-domain works, and best-sellers, all of which can be wirelessly downloaded at a moment's notice, and to scores of magazines and newspapers, which show up on subscribers' devices automatically. They're also giving adventurous authors and publishers new ways to organize and market their creations. A California startup called Vook, for example, has begun to package cookbooks, workout manuals, and even novels with illustrative video clips, and it's selling these hybrids of video and text to iPhone, iPad, and iPod Touch owners through Apple's iTunes Store.

KINDLE 2
Amazon

NOOK
Barnes and Noble

READER DAILY EDITION
Sony

QUE PROREADER
Plastic Logic

iPAD
Apple

Unfortunately, you can't get away with charging hardcover prices for an e-book, which makes it hard to see how traditional publishers will profit in a future that's largely digital. As a result, book publishers are facing a painful and tumultuous time as they attempt to adapt to the emerging e-book technologies. The Kindle, the iPad, and their ilk will force upon print-centric publishers what the Internet, file sharing, and the iPod forced upon the CD-centric music conglomerates starting around 1999—namely, waves of cost cutting and a search for new business models.

Publishers are lucky in one way: the reckoning could have come much sooner. From 1999 to 2001, I worked for NuvoMedia, a Silicon Valley startup that developed a device called the Rocket eBook. The Rocket and its main rival at the time, the Softbook Reader from Softbook Press, prefigured the current generation of e-book devices. Owners could shop for books from major publishers online, download the publications to their PCs, and then transfer them to the portable devices, which had monochrome LCD screens that showed one page of text at a time.

But three factors conspired to kill these first-generation e-readers. First, book publishers, fearing that digital sales would cannibalize print sales, offered only a limited catalogue of books in electronic form and charged nearly as much for Rocket and Softbook editions as they did for hardcovers. Not surprisingly, consumers demurred, which in turn discouraged publishers from offering more titles digitally. Second, the technology wasn't quite ready for mass adoption. The devices weren't small or thin enough to be truly portable, and the book-buying process was convoluted. Third, NuvoMedia and Softbook Press were acquired and then combined by a larger company, Gemstar, that was distracted by other issues and let its new e-book division languish, eventually closing it down.

Business conditions are very different today. For one thing, there are more big players with an interest in seeing the e-book business blossom, including Sony, Amazon, Barnes and Noble, and now Apple. Using their pull with publishers, these companies have assembled huge catalogues of e-books—Amazon has nearly half a million commercial titles—and they've kept prices lower, in the $10-to-$15 range for new trade books.

Just as important, mobile computing technology has improved drastically. Cheap 3G data access is the biggest advance. Now that readers can browse, purchase, and download e-books and periodicals directly on their devices, they can access new material almost instantaneously, without having to be near a desktop or laptop computer with an Internet connection. Having owned a Kindle 2 since May 2009, I can testify to the allure of this feature: I've bought a couple of dozen more e-books for my Kindle than I would ever have ordered from Amazon in print form in the same period.



PAPER BOY: SUPERSTOCK/GETTY IMAGES

Today's wireless e-reading devices fall into two groups, each with its strong points. The "electronic ink" devices all use black-and-white electrophoretic displays manufactured by Prime View International. (The Taiwanese display maker acquired the company that developed the technology, MIT spinoff E Ink, in 2009.) The $259 Kindle 2 is the best-known of these products, but Barnes and Noble's identically priced Nook and the $400 Sony Reader Daily Edition offer similar functions. The Kindle DX ($489) and the forthcoming Plastic Logic Que proReader (expected this summer, starting at $649) have larger screens and are intended mainly for reading textbooks and business documents. The Prime View screens on these devices depend on reflected ambient light, which gives them two advantages: they're easier on the eyes than backlit LCD screens, and they use far less power. Their batteries can last for days, and sometimes weeks, between charges.

In the last year, however, devices with LCD screens have reëmerged as credible e-book readers. Apple's iPhone, iPod Touch, and iPad are leading examples. The LCD screens use battery power faster, but they have the important advantage of being able to show moving images and full color, capabilities that are still at least a year or two away for electrophoretic screens.

For book publishers, color screens are interesting but probably not revolutionary. Vook titles like *The Breakaway Japanese Kitchen* ($4.99), a cookbook that bundles recipes with related instructional videos, provide a taste of what's possible. But with most long-form writing, the words are paramount. If their purpose is to stimulate the mind's eye, then color and animation are overkill, which is why I doubt that the iPad will wholly undercut the market for the Kindle-style devices.

For magazine, newspaper, and textbook publishers, on the other hand, the iPad and the wave of tablet devices just behind it create enormous opportunities. Magazines are distinguished from books not merely by their periodical nature and their bite-size articles but by their design. If digital-age readers still want information that's organized and ornamented in the fashion of good magazines—and there's no reason to think they don't—then devices that mimic the form and ergonomics of old-fashioned print pages will be needed to deliver it.

But to succeed on the new platforms, publishers will have to innovate, not simply imitate established media: they will have to move beyond the current crop of static digital magazines. The problem with most of the publications built on e-magazine platforms from Zinio, Zmags, and other startups is that they are simply digital replicas of their print counterparts, perhaps with a few hyperlinks thrown in as afterthoughts. Publishers should look for better ways to use tablet screens such as the iPad's, with its multitouch zooming and scrolling capabilities, and to make their content interactive.

There are many reasons, however, to suspect that the transition to the new distribution technologies will be rocky for the traditional publishing industry. For one thing, publishers may not be able to charge as much as they'd like for electronic editions. Kindle customers have frequently boycotted e-books priced above $9.99, and publishers' plans to charge up to $14.99 for

e-books sold through Apple's iBooks application have raised a serious outcry.

Magazine and newspaper buyers, too, have been trained to expect lower prices for digital editions. The *New Yorker* costs $35.88 per year on the Kindle, compared with $39.95 for a print subscription and $234.53 on newsstands. The $0.75 price tag on the Kindle version of the Sunday *New York Times*, whose newsstand version costs $5 or more, gives me a larcenous thrill every weekend. (And obviously, I can read newspapers on the Web, at least for now, and pay nothing.) On top of all that, there is little information yet about how readers respond to the ads inserted into the e-reader versions of magazines and newspapers, or how much publishers will be able to charge for the advertisements. And generating elaborate interactive content for digital periodicals will almost certainly drive up production costs.

The new digital reading platforms do, of course, provide an upside for traditional publishers: the technology will give them the opportunity to package material in surprising new forms that could attract new audiences.

In the best scenario I can envision for the publishing industry in 2020, basic text-centric digital content (nonfiction books, novels, daily news) will be so accessible and cheap that it will actually turn more people into regular readers, the way dime novels did in the 1870s and paperbacks did in the 1940s. In this way, publishers could begin to make up in volume what they will inevitably sacrifice through lower prices. But at the same time, they will be creating compelling multimedia experiences and packaging them at higher prices. After all, consumers who are willing to drop $14 to see *Avatar* in 3-D ought to be willing to spend the same amount on an edition of *Hamlet* souped up with video clips of Olivier, Jacobi, or Branagh. Maybe. TR

WADE ROUSH IS THE CHIEF CORRESPONDENT AT *XCONOMY* AND A FORMER SENIOR EDITOR FOR *TECHNOLOGY REVIEW*.



OPERATING SYSTEMS

A Less Personal Computer

GOOGLE'S NASCENT OPERATING SYSTEM WILL BE FAST AND SAFE. BUT IN RETURN, YOU'LL BE ASKED FOR YOUR PERSONAL DATA.

By SIMSON L. GARFINKEL

CHROME OS
Google
Release date:
Late 2010

In Web parlance, "chrome" is the part of the browser that surrounds the page: the address bar, the "Back" button, and those all-important bookmarks. Chrome is also the name of the Web browser that Google introduced back in September 2008, and—adding to the confusion—Chrome OS is the name of a new operating system that Google announced in July 2009 and expects to ship later this year.

The naming scheme is no accident. It reflects Google's ambition to create an operating system that is all but indistinguishable from the browser. Gone will be the normal files, directories, and applications. Instead, Chrome OS will put Google's cloud computing infrastructure—services and applications delivered over the Internet from its vast array of servers—at the heart of practically everything you do. Within a few years, Chrome OS could become the planet's simplest, fastest, and safest environment for personal computing. But there's a catch: it will also make Google the gatekeeper of your personal information. It could let Google delve further into your data to make its online advertising business more profitable than ever.

Chrome OS represents a radical new direction for computers. Today's major operating systems—Windows, Mac OS, and Linux—are all based on the 1980s model of the workstation. They're designed to run on powerful hardware, storing all the user's data and programs on a nearby hard drive. Even the Web, as invented in 1989 by Tim Berners-Lee, was merely an extension of this computing model—a better tool for finding data on the network and bringing it to your computer. But people don't use their computers that way anymore. At least, not people running popular Internet applications like Facebook, Gmail, and YouTube. When you use these applications, your data is stored in some distant data center—it's crunched in the cloud, and only copied to your computer for viewing.

You can download Chrome the browser and run it on Mac, Windows, and Linux

JASON SCHNEIDER

operating systems—and if you do, you'll find that it's noticeably faster than Apple's Safari, Microsoft's Internet Explorer, or Mozilla Firefox. Chrome also has less "chrome" than those browsers—no thick borders, no button bars or status lines. Google says that its vision is for the browser to get out of the way so that you can get closer to your data.

Chrome OS extends this strategy. It will be a Web browser running on top of a hardware-controlling Linux kernel, and not a whole lot else. Chrome OS should take up less than a gigabyte of your computer's hard drive, and the operating system will boot in seconds. It won't have a "Start" button—it will just have the Google home page, with links to your favorite Internet applications. Panels will appear on the side of the main window when you connect the laptop to your digital camera or when you find a new wireless network.

The minimalist design makes Chrome OS ideal for netbook computers that have modest memory and processing power. Several netbooks already ship with lightweight browser-only operating systems that users can run as an alternative to Windows. Chrome OS is similar, but it will be tightly integrated with Google's cloud-based services. After you log in to Chrome OS with your Google username and password, Google Docs will be there to let you edit and store documents, and Gmail will take care of your e-mail.

Today, you can download and run Chromium OS, a proof-of-concept prototype of what Chrome OS might be in a few months. I don't advise it: Chromium OS is just not ready. But several computer makers, including Samsung and Acer, have announced plans for Chrome-powered netbooks, and Google may yet deliver a Chrome OS–powered netbook computer that's built, like the Nexus One cell phone, to the company's own hardware specifications.

Google's engineers have explained that Chrome OS will use your computer's hard drive as a cache, making copies of whatever you're working on so that you won't burn up your netbook's wireless data plan (or your batteries). All that personal data will be encrypted, so you won't need to worry if you happen to lose the machine. And if for some reason your computer gets corrupted—perhaps by a virus—you'll be able to wipe it and start over without losing any work at all, since your data is stored in the cloud.

If you're a Google fan, employee, or stockholder, you'll see Chrome OS as the latest of the company's efforts to provide the best experience for users. If you're a competitor, you're probably more apprehensive to see Google extending its reach into operating systems. And if you're a privacy activist, like me, this move probably reinforces your biggest fears about the Internet giant: true to its mission statement, it really is after all the world's information.

Remember when, back in the 1990s, Microsoft tried to exploit the power that came with being the world's dominant PC software company to make itself into the most important provider of Web browsers, Web servers, and Internet services? The same thing could happen again, only in reverse. Google, the king of Internet search and advertising, could use the strength of its Internet applications to muscle its way into your future netbook, and from there onto your desktop. Google's vast array of Web properties will work best with the Chrome OS—not because Google is engaging in any monopolistic practices but because the system has been designed from the ground up to run complex Web apps. And if you can do everything inside a Web browser, why would you want to pay for a bigger, slower computer that has to be painstakingly managed?

The convergence of Chrome and Chrome OS with Google's cloud-based services also represents a seismic shift in the world of privacy. In the 20 years that I've been writing about these issues, the most significant privacy threats have come from companies seeking to collect and sell personal information and governments trying to access those commercial data banks. Chrome OS changes the equation dramatically. Now, for the first time, consumers will be encouraged to store much of their personal information with a single company—a company that makes its money by mining user data. And all that personal information will be protected by nothing more than a single username and password. Worse, sometimes it might not be protected at all: after all, Google decided to enroll millions of Gmail users in Google Buzz without their permission, sharing many of their Gmail contacts in the process. Chrome OS users will no longer have to worry about storing, managing, or backing up their personal data. But what if Google's vast data bank gets hacked, accidentally leaked, or shared with a pernicious government?

Many people mistakenly think that Google's primary product is search, and that they are the company's customers. In fact, a whopping $22.9 billion of Google's $23.7 billion in 2009 revenues came from the sale of advertising. Google tracks and mines the behavior of its users in order to target its advertising more effectively. Consumer mouse clicks are Google's real product, and advertisers are its true customers. Chrome and Chrome OS will give consumers more incentive to hand their personal data over to the Googleplex, further increasing Google's inventory and click-through rates. And having access to that personal information will let Google do an even better job of targeting advertisements to users who are most likely to click.

Google's real customers—that is, all those companies that spend billions each month to use its advertising services—will no doubt be pleased. More advertising space translates into a lower cost per click. But for ordinary users it may not be such good news. Today, you can still run applications locally, and keep your data exactly where you want. In the future, if you want to be part of Google's revolution in personal computing, you may no longer have that choice. TR

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ENVIRONMENT

Terraforming Earth

IN THE FACE OF CLIMATE CHANGE, A FOUNDING FATHER OF THE GREENS ARGUES, THE MOVEMENT MUST EMBRACE WHATEVER WORKS—EVEN IF THAT HAPPENS TO BE NUCLEAR POWER, MASS URBANIZATION, OR GENETIC MODIFICATION.

By MARK WILLIAMS

The environmental left, futurist Stewart Brand argues in *Whole Earth Discipline*, needs to view the world afresh. Once it has done so, he writes, it is likely to see that many of its most cherished notions are inconsistent with reality. It might see nuclear power as a plausible answer to our need for carbon-free energy, for instance. It might decide that DDT isn't so bad after all. It might be more open-minded about ideas like genetic modification, mass urbanization, and geoengineering.

Fat chance, one may suspect. In his acknowledgments, Brand notes that his book began as a piece called "Environmental Heresies" in *Technology Review*'s May 2005 issue. The faithful subsequently assailed him for imagining an environmentalist movement that embraced, in his words, "Green biohackers, Green technophiles, Green urbanists, and Green infrastructure rebuilders." The reaction provided ample evidence for Brand's contention here that default green thinking is "too negative, too tradition-bound, too politically one-sided for the scale of the climate problem."

WHOLE EARTH DISCIPLINE: AN ECOPRAGMATIST MANIFESTO
By Stewart Brand
Viking, 2009

Brand's position is notable because of his historical significance: he was the lifestyle guru who, in 1968, launched the *Whole Earth Catalog*, a publication whose covers often featured a picture of Earth seen from space and whose pages advocated the transformation of the planet through people's use of ecologically friendly tools. The publication continued into the 1990s and did as much as anything else during the last century to introduce eco-awareness to the masses.

Forty years ago, Brand believed cities were bad things, and the good thing—for Spaceship Earth, especially—was a rural lifestyle. Now, he passionately believes that cities are beneficial for both people and the planet. Then, Brand was antinuclear. Now, he writes: "Greens caused gigatons of carbon dioxide to enter the atmosphere from the coal and gas burning that went ahead instead of nuclear."

A statement like that amounts to an apostasy of sorts, and *Whole Earth Discipline* presents Brand's reasons for it. Given the question in any reasonable reader's mind—if Brand was wrong then, why is he right now?—this occasionally makes for droll reading.

Overall, however, Brand deserves credit for forthrightly stating that "when the facts change, I change my mind." He deserves credit, too, for asking to be held accountable for his book's predictions and for providing a website, Longbets.org, where one can go to tell him that he's wrong.

What changed his mind? Reality. Brand is a cofounder of the Global Business Network (GBN), a consulting firm that offers multiple scenarios, prepared by experts and insiders, to help companies, nongovernmental organizations, and governments plan strategically. One frequent GBN client has been the Pentagon's Office of Net Assessment, directed by the 88-year-old semilegendary futurist Andy Marshall.

In 2003, Marshall's office asked GBN for scenarios of abrupt global climate change. The data, from temperature indicators embedded in ancient Arctic ice, showed that temperatures had been known to shift with shocking speed. Brand realized, he says, that "climate change wasn't something remote, but could happen anytime—and *fast*." Our species has burned half a trillion tons of carbon since the Industrial Revolution began and could burn an equal amount in the next 40 years as China and India arrive at the First World banquet table, Brand realized. He understood that the planet might warm as much as five degrees before the end of the century. The most recent data support him: a 2009 study by the MIT Joint Program on the Science and Policy of Global Change indicates a median probability that Earth's surface temperature will rise 5.2 °C by 2100. One of the coauthors, Ronald Prinn, reports: "There's significantly more risk than we previously estimated."

Brand acknowledges that the consequences of climate change and climate policies remain uncertain: some stabilizing factor in the planetary ecosystem might mitigate the heating effects of our carbon emissions. "Counting on that, though, would be like playing Russian roulette with all the chambers loaded but one," he writes.

Hence, Brand has come to the position that humanity must be unbiased in its resolve to do whatever works. He opposes doctrinaire forms of environmentalism like the campaign to globally ban the pesticide DDT—a decision that, according to malaria expert Robert Gwadz of the National Institutes of Health, contributed to the deaths of 20 million children worldwide. Most pernicious, in Brand's view, greens have resisted nuclear power, claiming that renewable sources of energy like wind and solar will one day generate all the grid electricity we now derive from fossil fuels.

Given the current capabilities of those renewable technologies, Brand thinks, that's highly unlikely. A large coal-fired plant, a hydroelectric power station, and a nuclear reactor each might have one gigawatt (a billion watts) of generating capacity. To achieve the same capacity, a wind farm would need to cover more than 200 square miles; a solar

array, more than 50. That's a *big* footprint for renewables.

Admittedly, those estimates are disputed. Michael Totten, chief advisor on climate and energy at Conservation International in Arlington, VA, says that wind turbines have the smallest footprint of all energy technologies and that all current U.S. electricity consumption could be met with 400,000 turbines, each with two megawatts of capacity, placed over just 3 percent of the 1.2 million square miles of the Great Plains. If those turbines were hypothetically squeezed into one space, the footprint would cover just six square miles.

Mark Jacobson, a Stanford professor of civil and environmental engineering, confirms Totten's numbers. Footprint,



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WHOLE EARTH DOLLARS In a June 1971 photo, Stewart Brand celebrates the "last" edition of the *Whole Earth Catalog* by donating $20,000 in cash in San Francisco. Publication would continue occasionally into the 1990s.

Jacobson says, shouldn't be confused with spacing—the area between devices or around generator plants, which is usable for multiple purposes, like farming or wildlife refuge. If 50 percent of the world's energy needs were met by wind in 2030, Jacobson says, the footprint would be less than 50 square kilometers, although the spacing would require 1 percent of the planet's surface. Totten says, "Brand's arguments are blatantly wrong about wind and solar, as though he simply assembled in book form what he's heard over the years from GBN's biggest customers."

Arguably so. But asked about nuclear power, Totten invokes the prospect of Chernobyl-style meltdowns and reactors smashed open by terrorist-piloted planes. Reminded that these are technical impossibilities for modern reactor designs, he switches to an economic argument: nuclear plants are so expensive that the industry always requires government subsidies *(see "Nuclear Power Renaissance?" November/December 2009 and at technologyreview.com)*.

But it's notable that in the 1970s, before regulations made construction costs skyrocket, nuclear energy provided America's cheapest electricity. Nor should we forget that France gets more than 75 percent of its electricity from nuclear power, emits two-thirds less carbon dioxide per capita than the United States, and is the world's largest net exporter of electricity—earning $4 billion annually—thanks to its very low cost of generation.

Brand says it's entirely predictable that many greens neither know nor are interested in educating themselves about recent developments like new reactors or cleaner fuel cycles: "As far as they're concerned, nuclear had been stopped, they're glad it was, and now that it's happening again, they're confused and upset." That observation strikes at the heart of the matter. If today Greenpeace and an entire generation of activists simply cannot accept that nuclear power might be the most credible source of carbon-free energy, it's because doing so would entail an almost unbearable recognition: that a very large part of their life's work has been fundamentally, disastrously wrong, and that by obstructing the transition to nuclear back in the 1970s, they bear direct responsibility both for global warming and for the hundreds of thousands of deaths that have since resulted from coal-related pollution. It is to Stewart Brand's credit that he can recognize that disturbing truth. TR

MARK WILLIAMS IS A CONTRIBUTING EDITOR AT *TECHNOLOGY REVIEW*.

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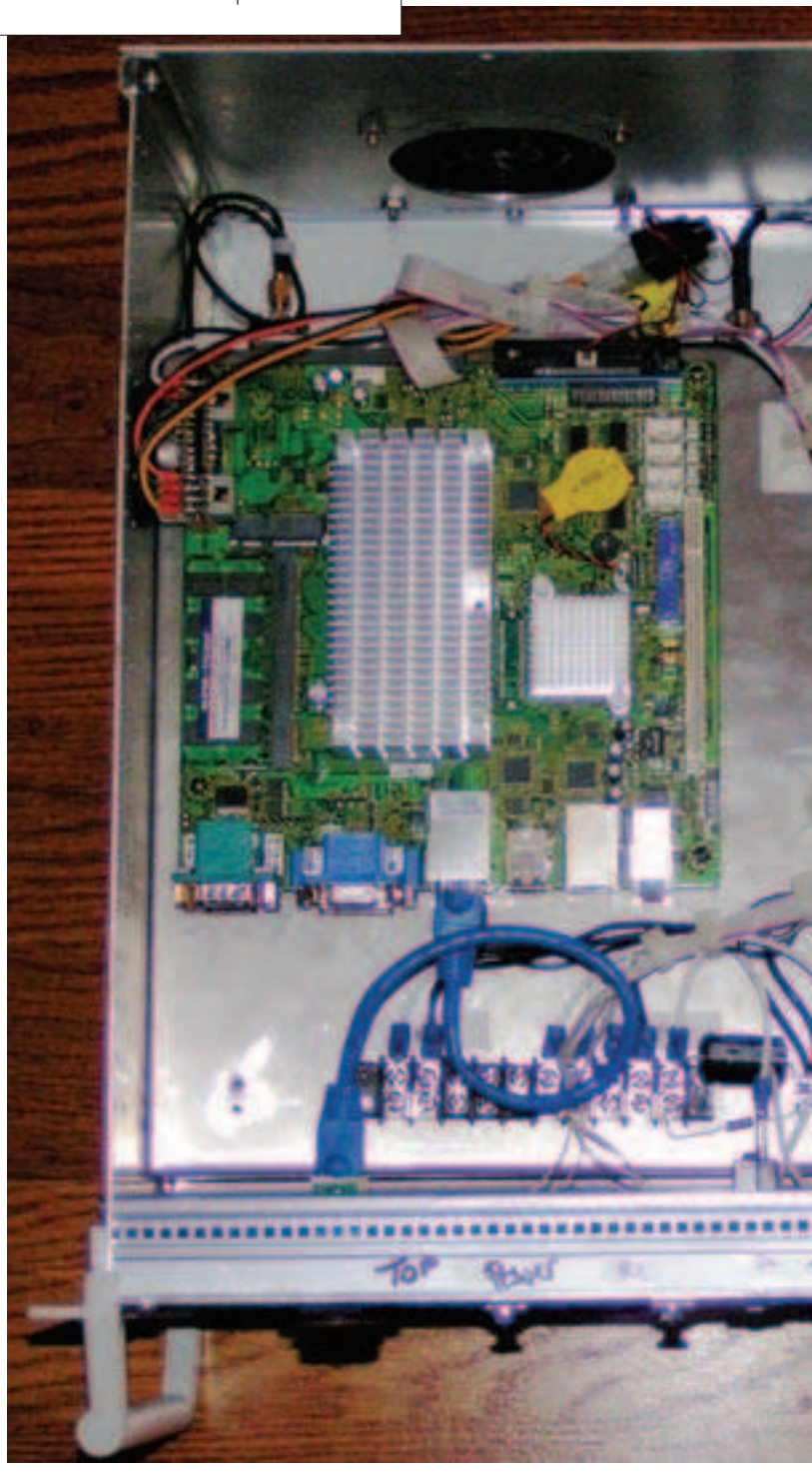
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POWER SUPPLY

The system deployed on Niue draws about 60 watts of power, supplied by three marine batteries of the type that many locals use on their boats. Because the system's power requirements are so low, Burgess says, a base station could also run on solar or wind power.



GSM HANDSET

OpenBTS re-creates the technology behind GSM (the global system for mobile communications), which is used by the majority of mobile phones in the world. Any GSM phone will "see" an OpenBTS network as a standard cell network and interact with it normally.

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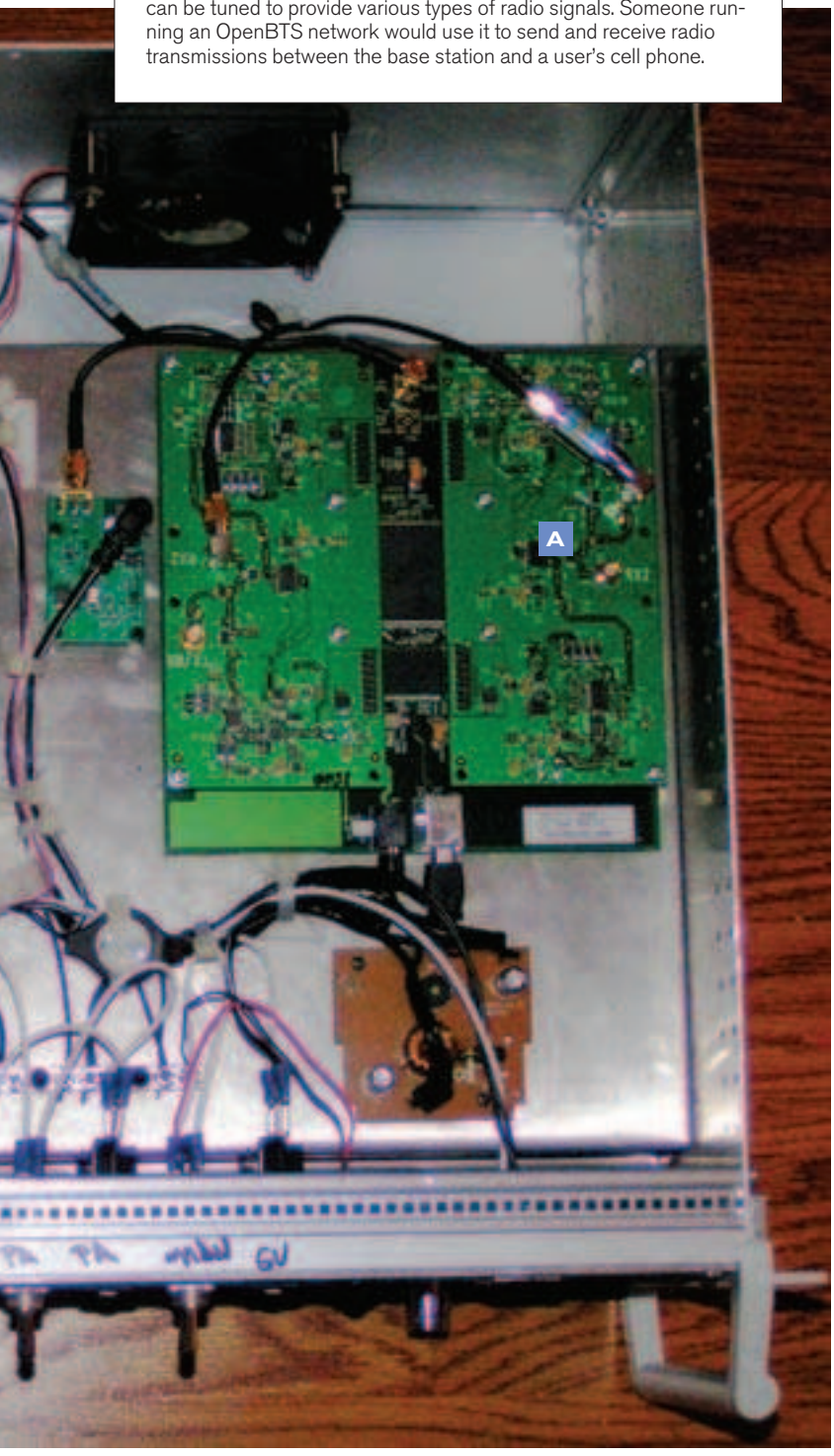
By ERICA NAONE

THE TASK of running a cellular network has usually been reserved for major carriers. But now an open-source project called OpenBTS is proving that almost anyone can cheaply run a network with parts from a home-supply or auto-supply store. Cell-phone users within such a network can place calls to each other and—if the network is connected to the Internet—to people anywhere in the world.

The project's cofounder, David Burgess, hopes that OpenBTS will mean easier and cheaper access to cellular service in remote parts of the world, including hard-to-reach locations like oil rigs and poor areas without much infrastructure. OpenBTS has already been used for cellular service at the Burning Man festival in the Black Rock Desert of Nevada and on the island of Niue in the South Pacific, among other locations.

A UNIVERSAL SOFTWARE RADIO PERIPHERAL

A relatively inexpensive piece of hardware, easily purchased online, can be tuned to provide various types of radio signals. Someone running an OpenBTS network would use it to send and receive radio transmissions between the base station and a user's cell phone.



ASTERISK SOFTWARE

A typical GSM base station, Burgess says, can't do anything without a suite of components that maintain databases, perform call-switching functions, and so forth. This infrastructure is expensive (typically around $250,000) and complicated to configure, and it needs to be stored in an air-conditioned room. Obviously, that's impractical in the kinds of places OpenBTS is designed for. As a result, the system replaces much of the physical infrastructure of the core network with VoIP software—in this case, an open-source program called Asterisk that can be installed on any off-the-shelf PC.



ANTENNA

Like any cell network, an OpenBTS system requires an antenna to facilitate signaling. Different types of antennas can be used, according to the range the operator wants the network to have.

IP CONNECTION

Cell-phone users on an OpenBTS network can reach each other even if the system isn't connected to the Internet, but reaching someone outside the network requires an Internet connection. On Niue, the group used five-gigahertz IP radios to link the BTS unit to Telecom Niue's wired Internet infrastructure, four kilometers away. Burgess says that response time can get a bit sluggish if the Internet connection isn't very good, but it doesn't take much bandwidth to make the system functional.

COURTESY OF OPENBTS

DEMO

Nanotube Fibers

SOLUTIONS OF CARBON NANOTUBES CAN BE USED TO MAKE STRONG, CONDUCTIVE FIBERS HUNDREDS OF METERS LONG.

By KATHERINE BOURZAC



1

In a Rice University lab, a black fiber the diameter of a human hair spools into a beaker of ether. Made up of pure nanotubes, the strand is the culmination of nearly a decade of experimentation. Chemical engineer Matteo Pasquali and his colleagues have spun nanotubes into fibers several hundred meters long, proving that commercially useful manufacturing techniques can be developed to produce macroscale materials from these cylindrical molecules of pure carbon.

Making carbon nanotubes into fibers was a particular dream of the late Rice professor Richard Smalley, who shared the 1996 Nobel Prize in chemistry for his discovery of the spherical carbon molecules called buckyballs. Individual nanotubes have remarkable properties: they're lightweight, they're strong, and they can be electrically conductive. But assembling them into large structures with these properties has been difficult.

In 2001, Smalley began trying to use liquid processing to spin carbon nanotubes into fibers that retained the tubes' electrical and mechanical properties over kilometer lengths—an idea that, he admitted, was "really lunatic extreme" *(see "Wires of Wonder," March 2001 and at technologyreview.com)*. Such fibers would be stronger than steel and more conductive than copper. Smalley



imagined them woven into cables that could efficiently carry electricity from remote wind and solar farms to populated areas—without losing energy to heat. Pasquali, who was part of the project from the beginning and took over after Smalley's death in 2005, acknowledges that he started out as a skeptic. "I thought that it was complete lunacy, because carbon nanotubes are not soluble in fluid—and I'm a fluid guy," he says.

Other researchers have made macroscale fibers from dry nanotubes, pulling them from vertical arrays or spinning them like wool as they emerge from a reactor. But the individual nanotubes in these fibers don't line up, and proper alignment is critical: tangled masses of the molecules don't carry electricity well, and they're not strong. Pasquali knew that nanotubes brought into solution would line up like logs floating down a river, resulting in well-ordered fibers.

The group had a breakthrough in 2004, when they reasoned that the methods used to manufacture Kevlar fibers, a component of bulletproof vests, might also work with nanotubes. Like nanotubes, the Kevlar polymer is long, thin, and difficult to dissolve in solution; the fibers are made by mixing the

TOMMY LAVERGNE







polymer with sulfuric acid and then shooting the solution through needles grouped like the holes in a showerhead.

The Rice researchers managed to dissolve only small amounts of nanotubes using sulfuric acid. But when they used chlorosulfonic acid—a so-called superacid—they could get high concentrations of nanotubes into solution. The tubes form a liquid crystal, in which they are already aligned—a tremendous advantage in making them into fibers.

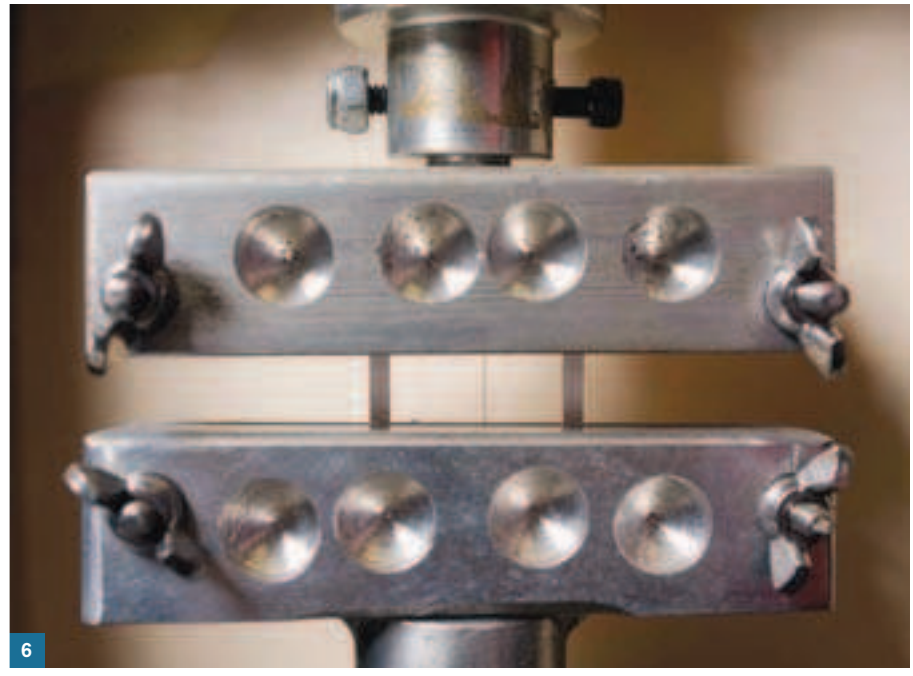
SPINNING A LINE

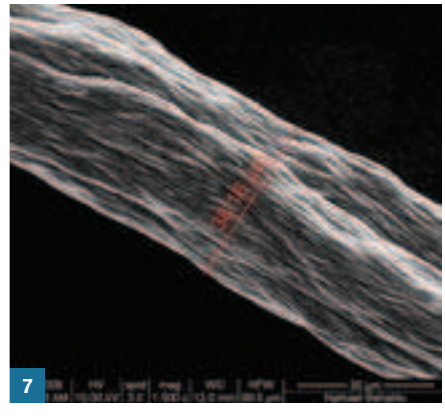
Pasquali's group starts its spinning process with single-walled nanotubes made in a nearby lab using a process originally developed by Smalley. In a high-pressure reactor where temperatures reach 1,000 °C, carbon monoxide alights on droplets of pure iron catalyst and decomposes. The carbon atoms build up into hollow cylinders about a nanometer in diameter and a few hundred nanometers long. These nanotubes emerge from the reactor in fluffy black drifts; they're kept in five-gallon buckets stacked to the ceiling, each holding just 200 grams.

Nanotubes made in this reactor contain traces of iron that must be removed before the tubes can be turned into fibers. Graduate student Colin Young fills a glass chamber with nanotubes that have been treated with oxygen in a furnace to oxidize the iron, mak-

Bottom left: Chemical engineer Matteo Pasquali, who spins carbon nanotubes into fibers in his lab at Rice University in Houston.
1. To remove iron left over from the manufacturing process, the nanotubes are placed in a chamber above a flask of boiling hydrochloric acid. Evaporated acid precipitates in the upper chamber and drips over the nanotubes and back into the flask below, carrying the iron with it.
2. Before the acid rinse (right) the nanotubes are fluffy; after (left), they're densely packed.
3. Pure nanotubes dissolved in a superacid sit inside a metal cylinder above a beaker of ether. A piston in the cylinder will force the solution through a needle suspended just above the ether.
4. The nanotube solution solidifies into a fiber as it streams from the needle and into the ether. This spinning process can yield fibers hundreds of meters long.







5. Graduate student Colin Young places a cardboard frame containing a nanotube-based fiber between the vises of a stretching apparatus.
6. The sides of the frame are cut and vises pull the nanotube fiber from either end until it breaks. This allows the researchers to determine the fiber's tensile strength.
7. An image taken using a scanning electron microscope shows that the nanotubes making up the fiber are all aligned.

ing it soluble. Inside a fume hood, he fastens the chamber over a flask of hydrochloric acid. He turns on a heating block under the acid to boil it. As it condenses and drips down onto the nanotubes, the acid dissolves the iron; the tubes are left untouched.

After their acid shower, graduate student Natnael Behabtu loads the nanotubes and chlorosulfonic acid into a stainless-steel tube fitted with pistons that rub the nanotubes uniformly in a single direction to encourage them to line up. The resulting viscous solution is 8 percent liquid-crystal nanotubes by weight.

He then detaches half of the chamber, and one of the pistons with it, and replaces it with a part that's been fitted with a spinning needle. The piston pushes the liquid through a glass filter (which prevents clogging), into the needle, and out into a waiting bath of diethyl ether. The acid is soluble in the ether, but the nanotubes aren't, so the result is a pure nanotube fiber, 50 to 100 micrometers in diameter and many meters long.

WWW Watch the Rice engineers spin nanotubes into meters-long fibers: **technologyreview.com/demo**

MEASURING UP

To measure the fibers' tensile strength, Young uses glue to tack a short length of fiber onto a cardboard frame. He clamps this into the metal vises of a stress tester, cuts the frame, and pulls the fiber from either end until it breaks. The fibers can currently withstand about 350 megapascals of pressure before failing—slightly less than a human hair, which is considered fairly strong for its diameter.

The fibers' strength depends on the friction generated where nanotube surfaces interact. Longer nanotubes generate more friction and, thus, stronger fibers. The Rice nanotubes—which Pasquali is using for the sake of convenience—are relatively short. But he's exploring partnerships with fiber-spinning companies and carbon-nanotube manufacturers who can provide additional spinning expertise and longer nanotubes. Pasquali hopes to ultimately increase the fibers' tensile strength more than tenfold.

There is still one major obstacle to realizing Smalley's dream of using nanotubes to remake the electrical grid. Pasquali's fibers have an electrical resistance of 120 microöhms per centimeter, about eight times greater than that of copper wires. The reason is that every method for growing nanotubes results in a mix of conducting and semiconducting versions. For nanotube fibers to carry enough current to displace copper, they'd need to be made up entirely of conducting nanotubes. The Rice group plans to make fibers from conducting nanotubes separated from the nonconducting tubes to determine whether such conductivities are possible. But today's sorting process makes the nanotubes too expensive for use in electrical transmission.

Pasquali remains optimistic, however, that this second challenge will be overcome, just as he solved the problem of spinning nanotubes into long fibers. And he's sure that when it is, strong, lightweight nanotube wires can at last replace the heavy and inefficient steel-reinforced aluminum cables used in today's power grid, just as Smalley imagined. TR

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Dr. Jeanette Norden is a neuroscientist, Professor of Cell and Developmental Biology in the School of Medicine, and Professor of Neurosciences in the College of Arts and Sciences at Vanderbilt University. Dr. Norden has won numerous university and national teaching awards and was the first recipient of the Chair of Teaching Excellence at Vanderbilt.

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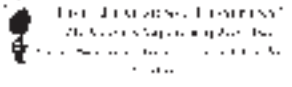
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Science Translational Medicine 2: 20ra14

Results: Researchers from Johns Hopkins University analyzed the DNA of tumors in patients with breast and bowel cancer and found regions of abnormal, rearranged DNA that served as unique biomarkers of each patient's disease. They then measured levels of cancer-specific DNA in one patient before and after treatment. The ratio of cancer DNA to normal DNA in blood samples dropped dramatically after treatment, but the marker was still detectable, suggesting that the patient should be monitored more closely for possible recurrence of the disease.

Why it matters: Cancer arises when a number of genetic alterations in cells allow them to grow uncontrollably. Tracking those alterations in a patient's cancer DNA could provide a new way of detecting small tumors or stray cancer cells that linger after treatment. Scientists say the DNA changes detected in the study will prove much more accurate than existing biomarkers such as the prostate-specific antigen (PSA) associated with prostate cancer, which may yield false positives because even healthy cells can produce the protein.

Methods: Researchers compared the genome sequence of patients' healthy DNA and DNA isolated from tumor tissue. After isolating unique tumor signatures, they developed a test that uses DNA amplification to measure the amount of tumor DNA and normal DNA in blood.

Next steps: To determine how the technology can be most useful in medicine, researchers will use it to analyze different tumor types as well as different stages of tumor progression. They are also working on automating the technique and reducing its cost.

Replacement Neurons

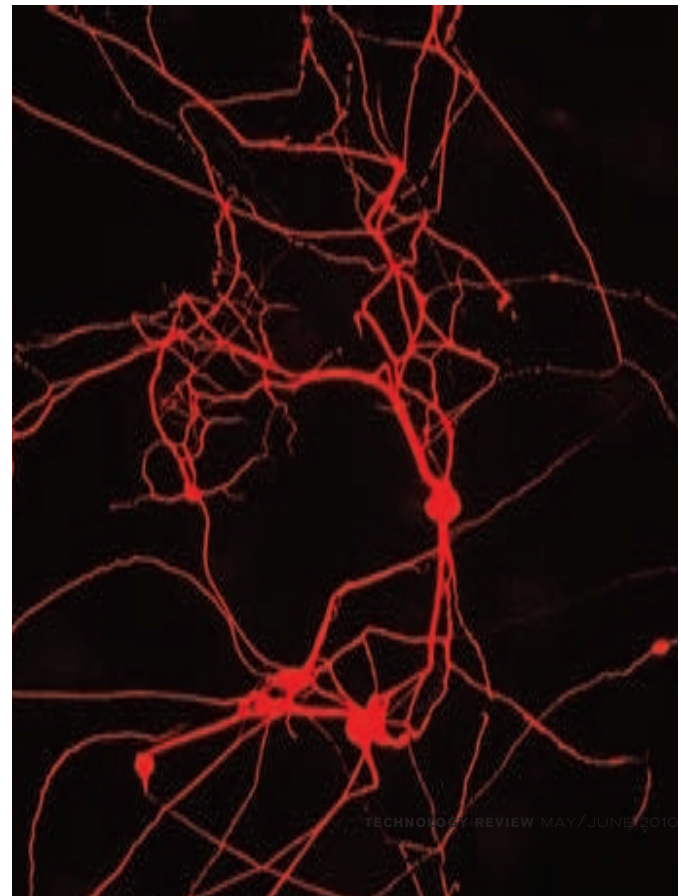
A SIMPLE GENETIC RECIPE REVEALS THE SURPRISING FLEXIBILITY OF ADULT CELLS

SOURCE: "DIRECT CONVERSION OF FIBROBLASTS TO FUNCTIONAL NEURONS BY DEFINED FACTORS"
Marius Wernig et al.
Nature 463: 1035–1041

Results: By making a few simple genetic tweaks, scientists can transform mouse skin cells directly into brain cells, without first returning them to the embryonic state required by previous methods. The resulting cells express neuron-specific genes, have the characteristic branching shape of neurons, and form connections both with each other and with regular neurons collected from the brain.

Why it matters: The research could someday offer an effective way to replace damaged neurons. Because brain cells derived from a skin graft would be genetically identical to the patient's own tissue, they wouldn't carry the risk of immune rejection associated with transplants. And scientists say the technique is faster than the existing approach to generating replacement brain cells from an individual patient: reprogramming adult cells to behave like embryonic cells and then prodding them to develop into neurons.

Methods: Scientists began by studying the genes for 19 transcription factors—proteins that bind to DNA and regulate expression of other genes. All were known to play a role in neural development



CELL TRANSFORMATION
A cocktail of three genes can transform skin cells into neurons (shown here in red).

THOMAS VIERBUCHEN/MARIUS WERNIG

and were found only in the brain. When the researchers used viruses to deliver two genes known to be particularly important for neural development into skin cells growing in a dish, they discovered that one of them had the power to convert the cells into what looked like immature neurons. They identified two additional genes that made the process faster and more consistent.

Next steps: The researchers are trying to repeat the process with human cells. They also plan to transplant the reprogrammed mouse cells into the brains of engineered mice that have a disease similar to Parkinson's. Those experiments could reveal whether the cells can function properly in the brain and relieve symptoms of the disease.

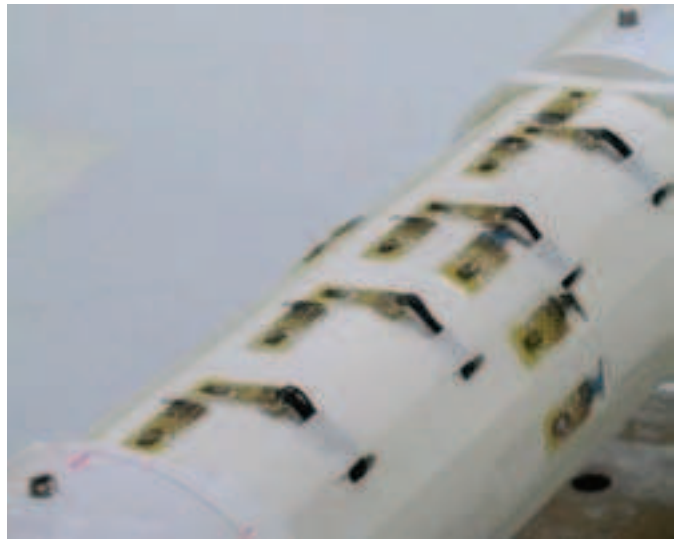
INFORMATION TECHNOLOGY

3-D Underwater Imaging

TECHNOLOGY INSPIRED BY FISH COULD HELP UNDERSEA VEHICLES FIND THEIR WAY

SOURCE: "ARTIFICIAL LATERAL LINE WITH BIOMIMETIC NEUROMASTS TO EMULATE FISH SENSING"
Chang Liu, Douglas Jones, et al.
Bioinspiration & Biomimetics 5(1): 016001

Results: Drawing inspiration from sensory cells in fish, researchers at Northwestern University and the University of Illinois have created a new kind of underwater 3-D imaging device. The invention uses an array of sensors to detect objects—in this case, a crayfish—on the basis of their movements. It can pinpoint the location of objects within a distance equal to half the length of the array.



ARTIFICIAL FISH Tiny sensors that imitate fish cells are arranged around a nine-centimeter PVC pipe.

Why it matters: The automated underwater vehicles currently used for surveillance, research, surveying, and other applications navigate either with cameras, which don't work well in murky water, or with sonar, which doesn't work well at close range. This new sensor could allow for more accurate navigation, particularly in confined spaces and unclear water.

Methods: Fish detect obstacles, predators, and prey with the help of sensory organs made up of arrays of specialized cells. These cells use tiny hairlike projections to sense water movement. The researchers used microfabrication techniques to mimic these cells. Each artificial sensor consists of a vertical silicon "hair," about 500 micrometers long, that is anchored to a piezoelectric device. As the hair moves, the piezoelectric material generates a voltage. The researchers developed an algorithm that interprets voltage signals from an array of the sensors to locate the source of moving water.

Next steps: The researchers will make larger sensor arrays and attach them to underwater vehicles for practical testing. They will also work to improve the resolution of the sensors so that they can detect objects farther away.

Faster Cloud Computing

RELIABLE SOFTWARE CAN NOW HANDLE DATA ON THE FLY RATHER THAN IN BATCHES

SOURCE: "MAPREDUCE ONLINE"
Tyson Condie et al.
Proceedings of the seventh USENIX Symposium on Network Design and Implementation, April 28–30, 2010, San Jose, CA

Results: Researchers have modified Hadoop MapReduce, a software platform designed to reliably process large amounts of data on a cluster of computers (as is necessary in cloud computing). The changes decreased by several orders of magnitude the time the software takes to process data, without sacrificing the reliability the technology is known for.

Why it matters: The earlier version of Hadoop was too slow to handle applications that require real-time responsiveness, such as providing near-instant updates about the traffic or sales transactions on a website. The new version could expand the range of applications that can run on distributed computers. It could also make applications that are run in the cloud more reliable by allowing managers to catch abnormal behavior as soon as it happens.

Methods: The researchers reduced the time it took Hadoop MapReduce to complete jobs by adapting a technique called pipelining. Ordinarily, Hadoop waits until one task is complete before it will start a second; that makes it easier to handle the failure of a computer in the cluster. With pipelining, data can be sent and processed continuously before the first task is complete.

Next steps: One of the researchers would like to develop the system further so that it can be used to cus-

YINGCHEN YANG

tomize Web-page layouts in real time in response to user behavior.

MATERIALS

Saving Silicon in Solar Cells

A MICROWIRE COMPOSITE COULD HELP REDUCE THE COST OF SOLAR POWER

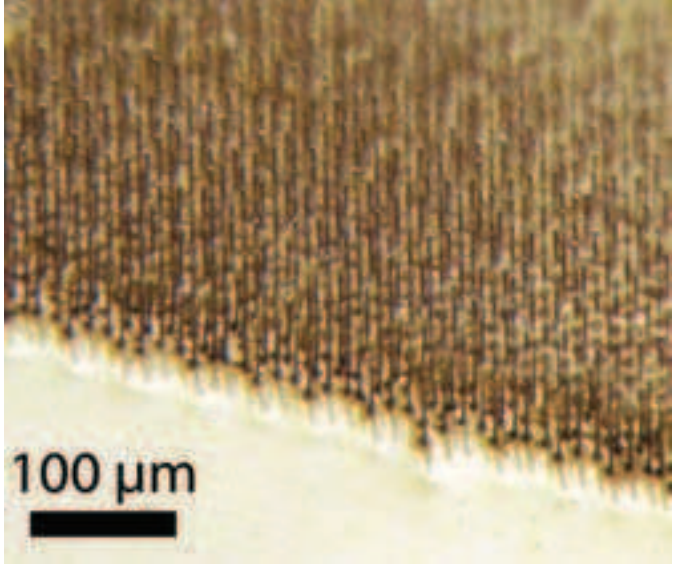
SOURCE: "ENHANCED ABSORPTION AND CARRIER COLLECTION IN SI WIRE ARRAYS FOR PHOTOVOLTAIC APPLICATIONS"
Harry Atwater et al.
Nature Materials 9: 239–244

Results: Sparse arrays of silicon microwires embedded in a rubbery polymer absorb as much light as the active layer in a high-performance solar cell but use just 1 percent as much silicon. The key to the material's efficiency is that highly reflective alumina nanoparticles in the polymer direct incoming sunlight toward the microwires. Computational models predict that the composite material could be made into solar cells that convert 15 to 20 percent of the energy in sunlight into electricity. This performance is close to that of the best cells on the market today.

Why it matters: Because it uses much less of the expensive silicon in high-performance solar cells without sacrificing the amount of light absorbed, the new composite has the potential to dramatically reduce the cost of solar power.

Methods: Microwires are grown from silane gas, at high pressure and temperature, on the surface of a reusable template that Caltech researchers designed after testing various geometric arrangements and calculating how thick and how far apart the wires should be. Next, the wires are treated with an antireflective coating, and a polymer mixed with alumina nanoparticles is poured over them. When it solidifies, the polymer can be peeled off the template, taking the array of silicon wires with it. Incoming light bounces off the nanoparticles until it can be absorbed by a wire. If any light makes it through the material without being absorbed, a silver backing reflects it back in.

Next steps: So far, the researchers have made small arrays—on the order of several square centimeters. Once they're able to make the arrays hundreds of times bigger, they will build solar cells by adding layers such as the electrodes needed to extract electrons and generate power.



LIGHT ABSORBER Silicon microwires (vertical dark lines) are surrounded by a polymer that helps them capture more sunlight.

HARRY ATWATER

Ultrafast Graphene

IBM CREATES LARGE ARRAYS OF TRANSISTORS THAT ARE SPEEDIER THAN SILICON

SOURCE: "100-GHZ TRANSISTORS FROM WAFER-SCALE EPITAXIAL GRAPHENE"
Yu-Ming Lin, Phaedon Avouris, et al.
Science 327: 662

Results: Researchers at IBM have made graphene transistors that operate at 100 gigahertz, 10 times as fast as the speediest silicon transistors of the same size and faster than previous graphene transistors. They produced large arrays of these transistors, using methods that are compatible with semiconductor manufacturing.

Why it matters: Although graphene transistors made in earlier research have shown promising speed, the techniques used for making them haven't lent themselves to mass production. Because the new transistors are easy to make, they could be a practical substitute for conventional transistors in military communications, radar, medical and security imaging, and a variety of other applications that require high-frequency analog transistors.

Methods: The researchers heated a five-centimeter-wide wafer of silicon carbide until the silicon at the surface evaporated, leaving behind graphene, an atom-thick sheet of carbon. Then they used conventional lithographic techniques to lay down source and drain electrodes and a dielectric (or insulating) layer, resulting in a pattern of numerous transistors. The addition of a thin polymeric layer between the graphene and the dielectric layer kept electrical charges in the insulator from compromising the graphene's electrical properties, thus dramatically improving the transistors' performance.

Next steps: The researchers plan to improve upon their current work by building integrated circuits like those used in computer processors. They will also attempt to speed up the transistors further by making them smaller. So far, the graphene transistors they've made are 10 times the size of the best silicon transistors.

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2010 IEEE Conference on Innovative Technologies for an Efficient and Reliable Electricity Supply
September 27-28, 2010
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www.ieee-energy.org

The Very Large Impact of the Very Small

A BELL LABS VETERAN LOOKS INTO THE FUTURE AT THE START OF THE MICROELECTRONICS AGE

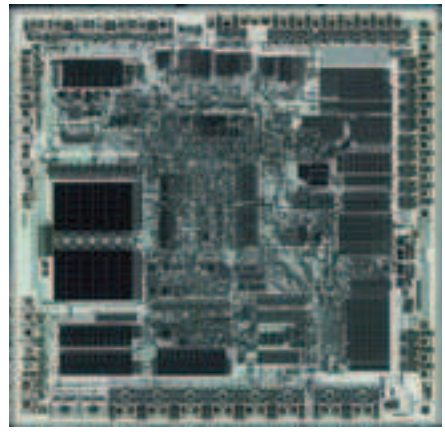
By MATT MAHONEY

Every year since 1960, when the integrated circuit industry began, the number of components per chip has about doubled. This phenomenal rate of progress has brought us to the era of "very large scale integrated" (VLSI) circuits. Today, over 150,000 components can be fabricated and interconnected on a single silicon chip about one-tenth the size of a postage stamp, and the number of components per chip can be expected to grow dramatically for at least another 10 to 15 years.

So it went in 1981, when John S. Mayo, a researcher and executive at Bell Labs who was part of the team that built the first computer to use transistors instead of vacuum tubes, described how VLSI was making powerful microelectronics possible. What Mayo described is known as Moore's Law—the prediction, in 1965, by Intel cofounder Gordon Moore that the number of components on a chip would double every two years. (Initially, Moore predicted an annual doubling.) In the 29 years since Mayo's essay, Moore's Law has held up nicely: the latest chips feature more than two billion components.

Even then Mayo saw that the microprocessor industry would maintain its level of innovation. He saw that engineers could use the power of the computer chips themselves to design chips that were even more powerful. He understood that complex, efficient computers could be used to design computers that were even more complex and efficient.

A primary example is computer-aided design (CAD). In the last five years, integrated circuits have become so complex that without the advanced analyses and extensive simulation techniques available through CAD, it would be virtually impossible to design VLSI chips. But with CAD,



JAM-PACKED This state-of-the-art (for 1982) Intel chip held 134,000 transistors.

even complex circuits can be designed in a few months with no real increase in labor.

The advances in fabrication and design drove down the cost of a digital logic gate to the point where the average person in 1981 could buy a cheap pocket calculator to do the same work that previously would have required a huge, expensive computer. Microprocessors were on their way to becoming ubiquitous.

Some discrete high-frequency components have been built with submicron dimensions, and there are indications that dimensions in the tens of nanometers (one-billionth of a meter) are technologically feasible. Such dimensions are 100 times smaller (10,000 times smaller in area) than the current chips and may lead to packing more than 1 billion components on each chip.

Mayo had joined Bell Labs in 1955, eight years after the first transistor had been invented there, so he had an insider's view of what cramming a billion transistors onto a chip would mean. He was especially excited about distributed computing—that is, networking—and telecommunications.

VLSI will make possible systems even more complex in hardware and simpler in software, opening a new area of software science—distributed software systems, wherein a whole family of computers of many sizes operates under centralized software control. ...

The impact of microelectronics on communications is nearly as profound. ... Electronic switchers now make it possible to forward calls automatically, to reach frequently called numbers through abbreviated dialing codes, to notify users of other incoming calls, and to conduct three-way conference calls.

The full implications for communications were beyond anything Mayo could have predicted. Cell phones, wireless networks, downloadable apps—in other words, many of the things we take for granted *(see Briefing, p. 69)*—were all made possible by the increasing power and availability of microprocessors. And yet Mayo clearly sensed the developments to come, even pointing out an early foray by the media into interactive content:

Other communications concepts are on the horizon. Advanced Mobile Telephone Service can provide service to large numbers of people in vehicles and is working well on a trial basis in Chicago. And the VIEWTRON system, on trial in Coral Gables, Fla., enables one to display on a television screen some 15,000 "frames" of information—some interactive—transmitted via telephone lines from a data bank. TR

CHRISTOPHER TARNOVSKY

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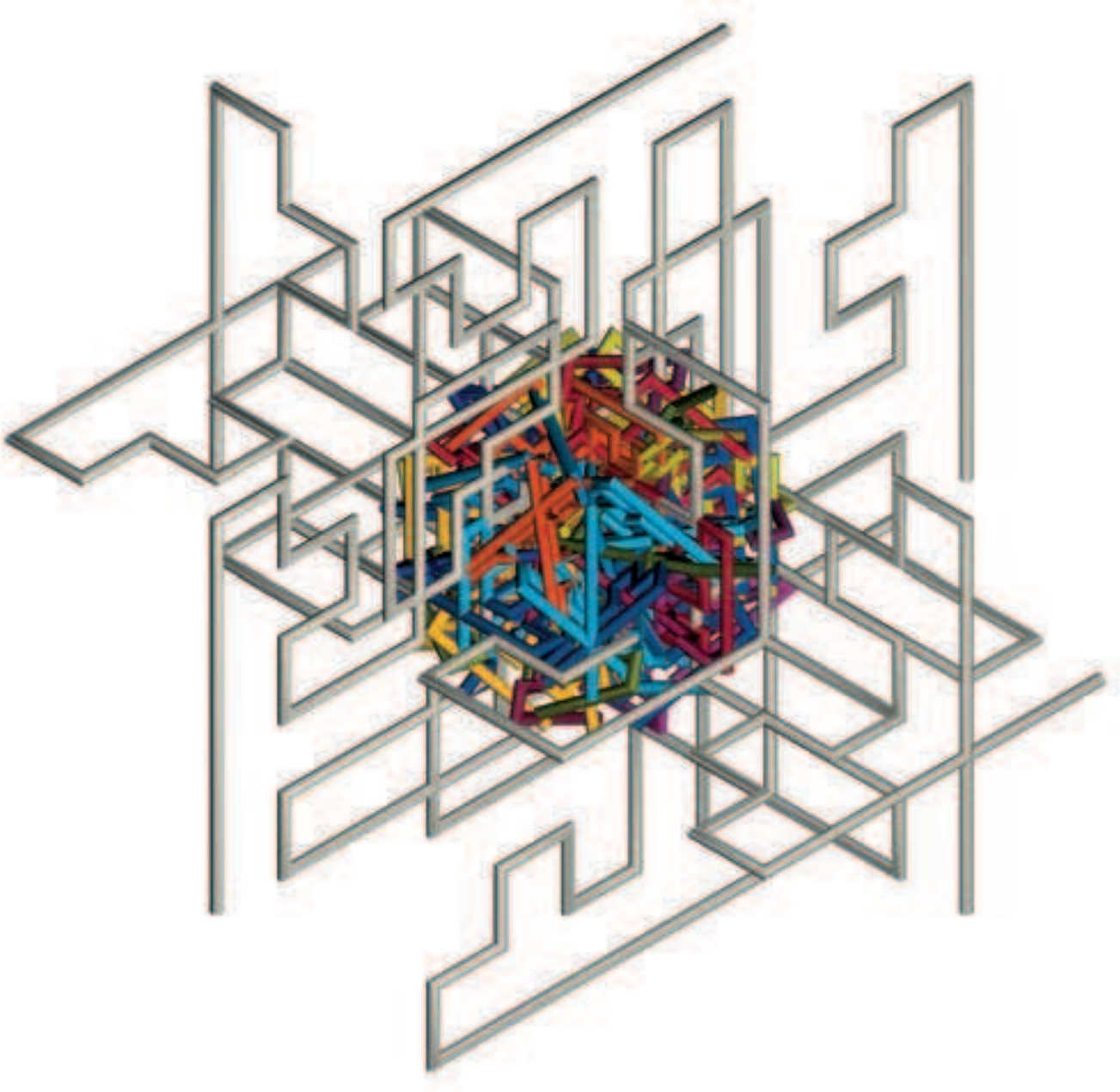
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Smarter technology for a Smarter Planet:

Why the old ways of working aren't working.

On a smarter planet, technology has made us more connected, but not necessarily more productive. As new global opportunities emerge, companies are finding that their internal processes aren't as dynamic as the marketplace requires. In fact, employees spend up to 25% of their time just looking for information that should be readily available to them. Managers require visibility across their company in order to make fast, informed decisions. IBM can help optimize business processes to align with the way people actually work and provide a contextual, information-rich environment. By combining elements of business process management, collaboration and SOA solutions, employees can act on real-time insights and locate the right people to seize new opportunities—helping to reduce costs.

A smarter business needs smarter software, systems and services.
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